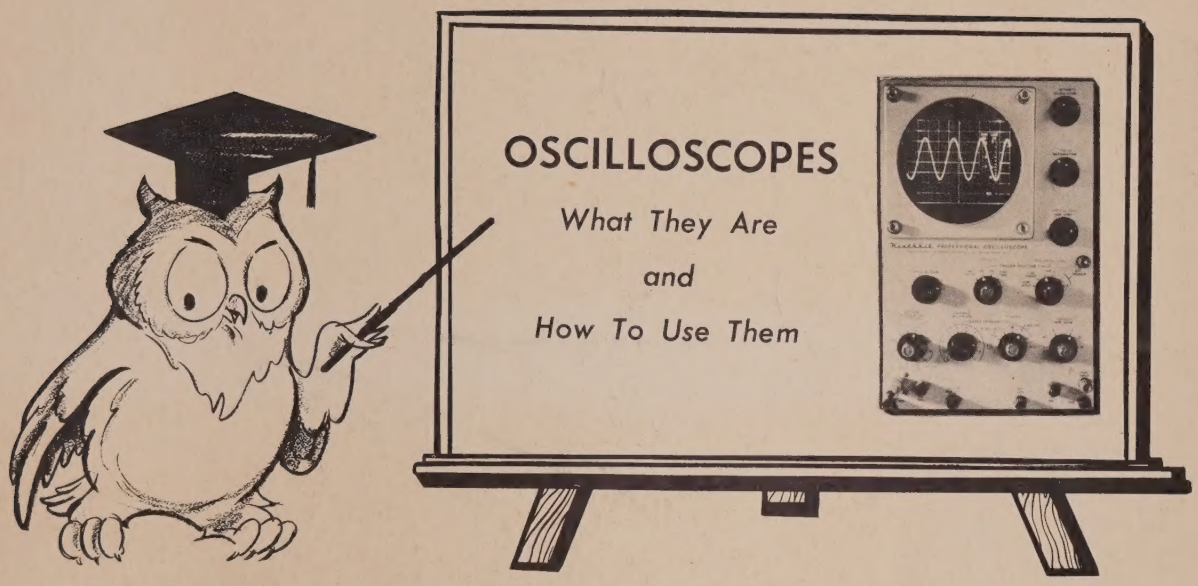

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PART ONE

INTRODUCTION

Our D39 and D39B courses have been available for several years with background on oscilloscopes and associated circuits. In addition, the D28 and D32 television series have covered some of the circuits and applications. In the meantime, newer scopes have been added to plant operations and more people have occasion to use them. Since many people in this category have not had the above courses, we have been asked to prepare a story on the general subject of scopes.

To properly use any scope, the basic principles of operation must be first understood. These principles are the same on the simplest or the most expensive scope, although the mechanics of implementing them may differ.

We will first endeavor to develop the principles as they apply to the use of the scope and we will temporarily ignore the circuit details necessary to the functioning of a complete instrument.

Pattern Presentation

Let us assume a small boy with a new flashlight which is very bright, and can be focused to a very narrow beam. Our little boy takes the flashlight into a dark room and starts to play. . . . First he points it at the wall and moves it up and down. (See Fig. 1.) A series of bright spots appear upon the wall. . . . He now moves it faster and a bright line appears. This is due to the fact that our eyes play tricks on us and retain an image for a fraction of a second. Thus, anything that repeats more frequently than about 16 times a second seems to us to be continuous, and is called "persistence of vision."

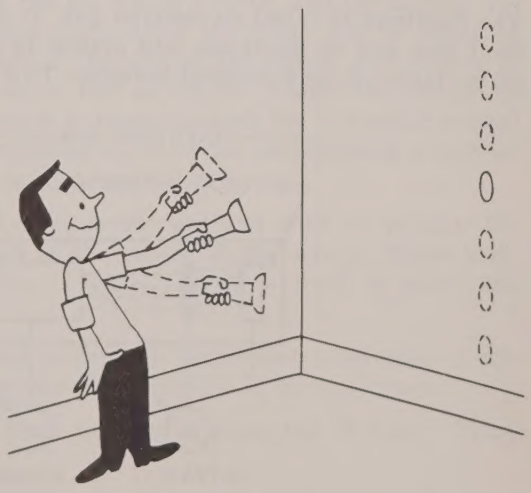


Fig. 1

Now if our little fellow moves his flash crosswise, we could see a horizontal line. Sooner or later this becomes tiresome and he soon combines the two motions. If he moves vertically and horizontally at the same time, it should not be difficult to visualize him tracing a circle, an ellipse, a square, etc.

Now let us replace the wall with a white bed sheet, and we will stand on the other side. We will engage him in a little game and say, "Up two and left one." He always starts from the center. (Fig. 2.)

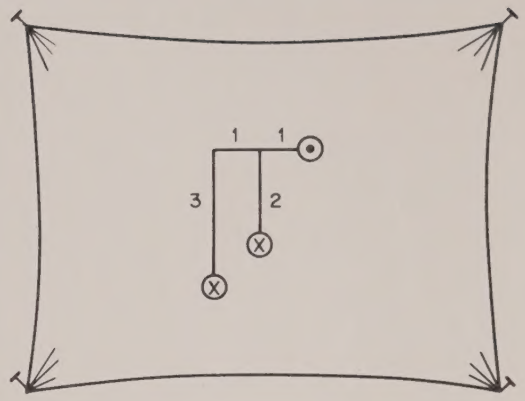


Fig. 2

We now say, "From there, right two and down three." We soon see that by combinations of the horizontal and vertical movements we can put the spot anywhere on the sheet we wish and form any sort of pattern we like. Unfortunately our little boy soon gets tired of the "game" and decides to take the flash apart.

What we have seen on our side of the sheet is essentially what is seen on the face of a cathode ray tube and the mechanism of accomplishment was quite similar.

Cathode Ray Tube

Certain substances, when struck by an electron will produce a momentary flash of light. These are called phosphors. They can be chemically composed to produce various colors and to retain the flash for various intervals. A glass surface, coated with a thin layer of phosphor, is the part of a cathode ray tube we normally see. It has a "medium" persistence. That is, when struck by an electron it will glow and retain the glow momentarily. Oscilloscope CR tubes generally glow white or blue but are sometimes a yellow green. This is our sheet so now we need the boy with the flashlight.

The flashlight is called an electron gun. It consists of a cathode to emit electrons, a grid to control their flow and an electronic lens system to concentrate, or focus, the electrons in a sharp beam — all contained in an evacuated envelope. This is shown in simplified form in Fig. 3.

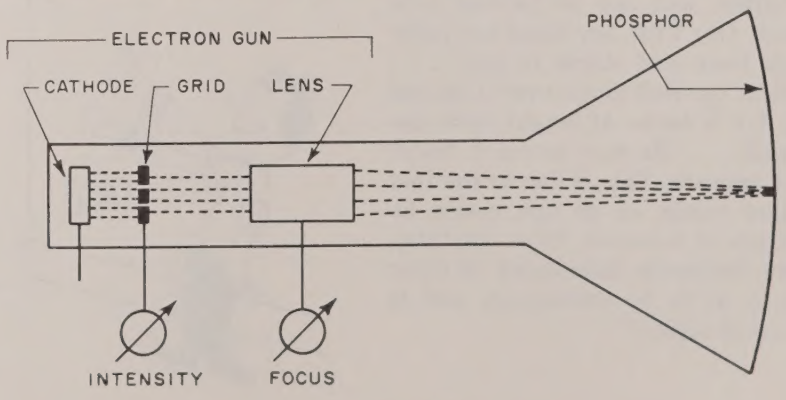


Fig. 3

By controlling the grid voltage, as in any electron tube, we can control the flow of electrons and thus the number striking the phosphor. This controls the brightness of the glow and on most scopes is called an INTENSITY control. The elements making up the lens also have a variable control which permits concentrating the stream of electrons into a sharp cone so that all strike the phosphor or "screen" at one tiny point. This control is generally marked the FOCUS control.

In practice, the INTENSITY and FOCUS controls tend to interact so that after adjusting one the other must be corrected. If not properly focused, a large soft blob of light appears on the screen or the tube is said to be "blooming."

If we leave our bright, sharply focused spot on the center of the screen, it will soon "burn" a brown spot on the phosphor so we must find a way to move it.

If we remember the law of charges, we know that a positive charge will attract electrons and a negative charge will repell them. So let us pass our focused electron stream or "beam" between a pair of horizontal plates. See the diagram in Fig. 4.

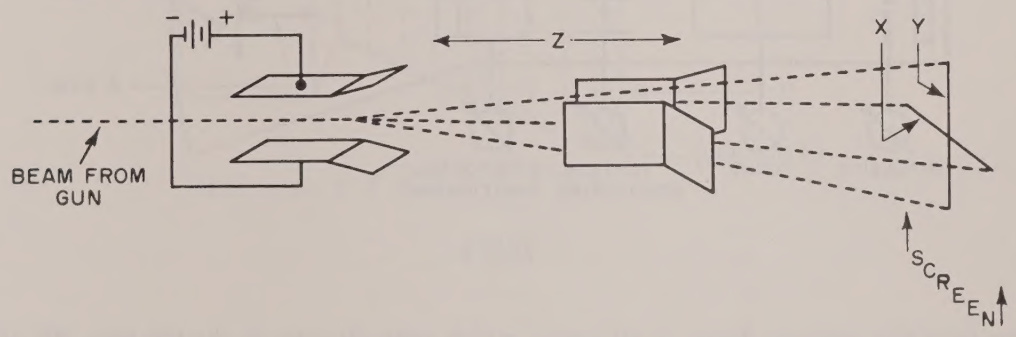


Fig. 4

If we connect a battery between the two plates so that the top one is positive and the bottom one negative, the beam will be deflected upward. If we double the voltage, the beam will be deflected twice as far. In other words, the deflection and movement of the spot up the screen is *directly proportional* to the deflecting voltage. Moreover, it will move as fast as we can change the voltage so long as we don't change it faster than it takes an electron to move through the deflecting plates! Thus, we begin to see a visual, dynamic voltmeter developing in which the movement of a spot on a screen is proportional to magnitude and polarity of a deflecting voltage.

If we reverse the polarity on the plates, the spot will move downward and with no voltage (or the same voltage) on the two plates the spot will appear in the center of the screen. These horizontal plates thus produce vertical deflection along the "Y-Axis." Input to them is called the VERTICAL, V or Y input.

Another pair of plates, mounted vertically, can be used to produce horizontal movement of the beam in the same manner. Input to these plates is called the HORIZONTAL, H or X input.

Sometimes signals are applied to the grid to vary the beam brightness along the "Z-Axis." Thus, this is usually called the Z input.

We can now see that by placing the proper potentials on the deflection plates we can move the spot anywhere on the face of the tube in the same way that we played the flashlight game.

Cathode ray tubes are carefully made but perfect alignment of the gun and deflection plates is not economically feasible. We therefore apply small adjustable voltages to these plates in order to center the beam before applying signal voltages to them. These voltages are adjusted with the VERTICAL POSITION and HORIZONTAL POSITION controls. The various inputs and controls are shown in Fig. 5.

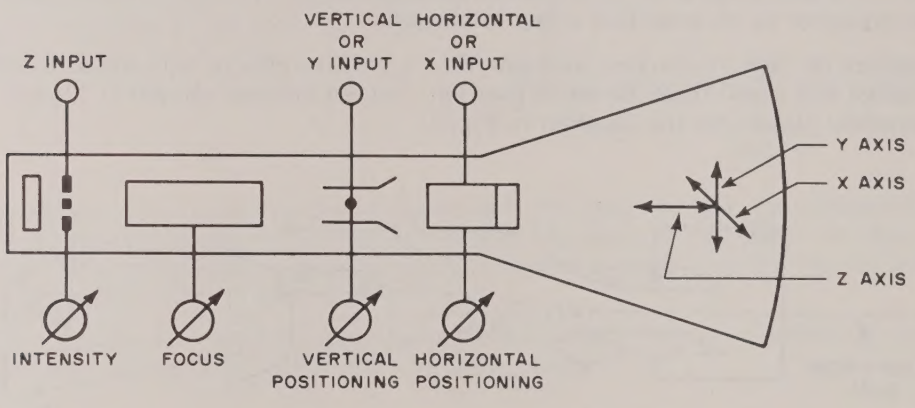


Fig. 5

We now have four controls, found on all scopes, which apply directly to the CR tube. We also have three input locations where we can apply signals. Let's see how we use them.

Deflection

In addition to being able to measure the magnitude of a voltage, a scope can also display its shape or wave form. To do this, we must take advantage of both "motions" available through the two sets of deflection plates. If we move the beam at a constant rate horizontally across the face of the tube, while we apply our signal to the vertical plates, the wave form will be plotted instant by instant. Due to persistence of vision and persistence of the phosphor, a visible trace will be seen of any repetitive signal unless the rate of repetition is very slow. In that case, only a portion of the trace will be seen. The way in which we obtain the constant trace or "sweep" across the tube face is with a "saw tooth" input to the horizontal deflection plates, as indicated in Fig. 6.

If the saw tooth starts by making the left plate positive with respect to the right plate, the spot will start to the left. As the saw tooth becomes less positive, the beam moves to the right, at a constant speed, determined by the straight line shape of the saw tooth and by its frequency. At time 9, the voltage rapidly reverses and the beam is returned to its starting point. The distance the beam moves across the tube face is controlled by the magnitude of the saw tooth "sweep" voltage. However, the time it takes is determined by the repetition rate of the sweep and the retrace interval which ideally is as near zero as possible. If the sweep repeats at a 1000 cycle rate, then the time of one sweep is .001 seconds. The sweep is therefore called a "time base" since by measurement across the horizontal line traced, we can determine any fraction of time. If the sweep is linear and .001 seconds long, then halfway across the sweep will represent .0005 seconds.

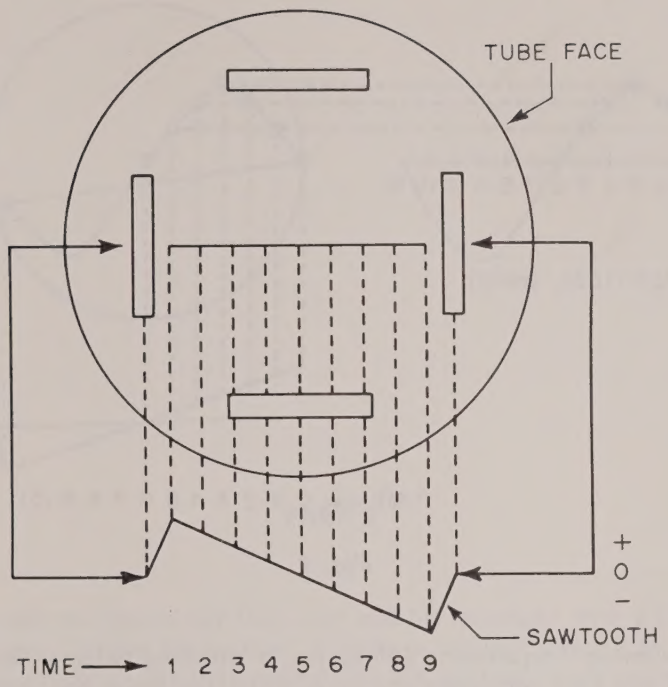


Fig. 6

Sweep generators generally have two controls — a COARSE and a FINE control. The COARSE control sets a range of repetition rate while the FINE control allows variation within that range. These are designated in either of two ways — "10 to 500,000 cycles" or "in milli-seconds and micro-seconds" of sweep duration.

Now let's see what happens when we apply a signal to the vertical plates. We will assume that the repetition rate is 1000 cycles per second and that the signal is also 1000 cycles per second of sine wave.

Looking at Fig. 7, we see that at time 0 the sweep voltage is maximum to place the beam at the extreme left of the screen while the signal voltage is zero so that the beam is on the vertical center. At time 1, the beam is moved to the right by the sweep and up by the signal to point 1. At time 2, the beam is moved over and up to point 2. At time 6, both the signal and sweep are at zero voltage and the spot is centered. Thus, we continue to trace the pattern until we reach 11-1/2 when the sweep voltage rapidly reverses moving the beam rapidly from right to left while the signal is going from a small negative voltage to zero or from point 11-1/2 to point 0 on the pattern. Thus, we have lost a bit of our pattern during the "retrace." The next cycle will be laid over the top of this one on the CR tube screen and a bright picture of the wave shape will be seen. The retrace will not be as bright since it is very fast and, therefore, fewer electrons hit any particular spot on the phosphor.

If desired, a voltage may be applied to the grid, or Z Axis, of the CR tube cutting off the beam during the retrace interval. This is called "blanking" of the retrace and on some scopes can be turned on or off with a panel-mounted BLANKING switch.

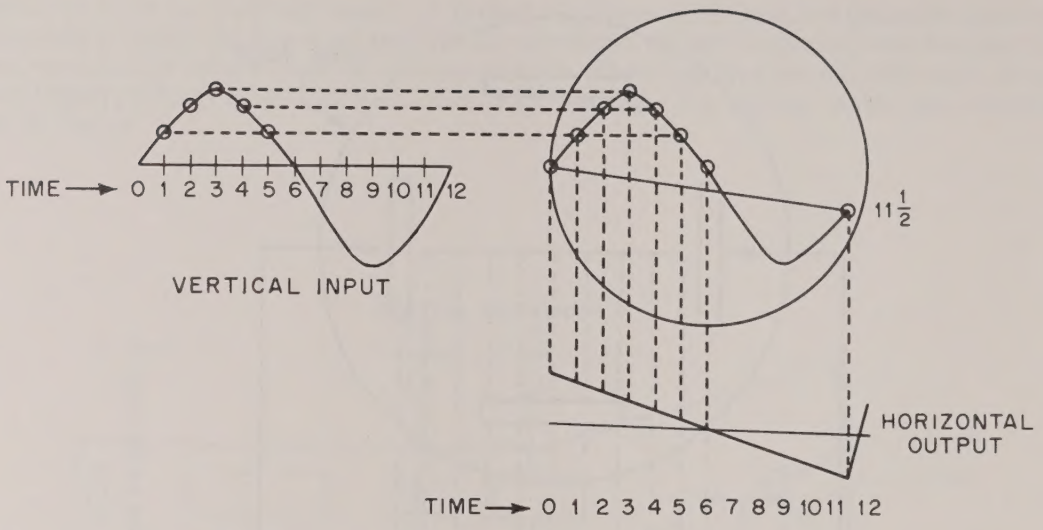


Fig. 7

If we now change the sweep frequency to 500 cycles, it will take twice as long to complete. Then our 1000 cycle signal will have completed one cycle while the beam has moved half way across the screen and two cycles will be displayed. In the same way a 333-1/3 cycle sweep will display 3 cycles and a 250 cycle sweep will display 4 cycles. Thus, if we remember the time relationship of the two inputs, we can control the form of presentation. It should also be apparent that if the two frequencies are not whole multiples of each other, a full cycle will not be presented and a "stable" pattern will not result since successive sweeps will not start at the same time point in the signal voltage. Try plotting a pattern, as we have done, when the signal frequency is 1000 cycles and the sweep frequency is 1500 cycles!

PART 2

Amplifiers

So far we have been able to replace our little boy and his flashlight with a CR tube; but to trace a pattern we require very "strong commands." A voltage applied directly to the deflection plates must be quite large to overcome the high velocity of the electron beam. A typical figure is in the order of 20 volts to cause one inch of deflection, or about 60 volts peak-to-peak. This is known as the deflection sensitivity. To increase the deflection sensitivity, we use amplifiers and this introduces problems.

(1) The first, and probably least important problem, is that of phase inversion. We would like positive signals to produce an upward deflection of the vertical trace. If our amplifier has an odd number of stages, the signal will be inverted. This can be quickly checked by momentarily touching the input with a 1-1/2 to 4-1/2 volt potential, properly poled, and observing the direction of the momentary beam movement. In the horizontal section we have a similar problem, since we want beam movement from left to right.

(2) A more serious problem is the limitation on bandwidth. Direct input connection to the deflection plates is usually of high impedance with little shunting capacity effect. The result is that very high frequency ranges are possible. Amplifiers, however, become complex if both high sensitivity and bandwidth are required. General purpose scopes have bandwidths of 300 to 500 kc while laboratory type instruments may pass frequencies up to 10 mc. These have complex video-type amplifiers. The effect of amplifiers will be discussed a little later.

Sensitivities likewise vary, depending upon the intended application, and are usually higher when the bandpass is restricted. A not uncommon sensitivity is 0.05 volts (RMS) per inch of deflection. A popular kit-type oscilloscope has a vertical sensitivity of 0.01 volts (peak-to-peak) per centimeter. The Tektronix scope, now being furnished in our testrooms may have a sensitivity of 5 millivolts per centimeter up to 9 mc!

Horizontal amplifiers generally have lower sensitivities and less bandpass since their major requirement is to handle the sweep voltage. This is usually of greater magnitude and of lower frequency than signal voltages. In the Tektronix scope, previously mentioned, the highest sweep frequency is 0.02 micro-seconds per centimeter. Thus it requires about 1/4 micro-second to traverse a 5-inch screen, or 4 mc. The vertical response of this scope is 10 mc.

(3) Another problem with conventional amplifiers is the loss of the d-c component of the signal. Any non-symmetrical signal, when amplified by an AC amplifier, will average to produce the same "signal area" above and below a zero voltage reference due to the coupling capacitors as shown in Fig. 8. Thus we lose the "reference" line in our scope presentation. This often makes signal an-

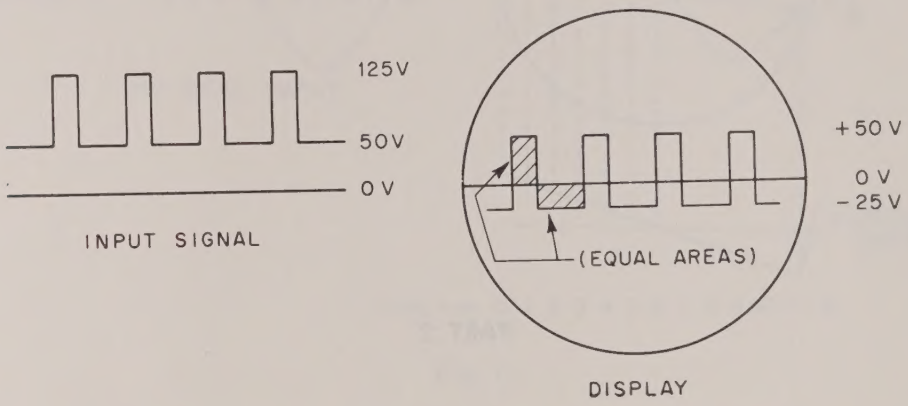


Fig. 8

alysis difficult. To avoid this problem d-c coupled amplifiers may be used so that the passband is lowered to 0 cps. In this way, a true display may be obtained which could look like Fig. 9.

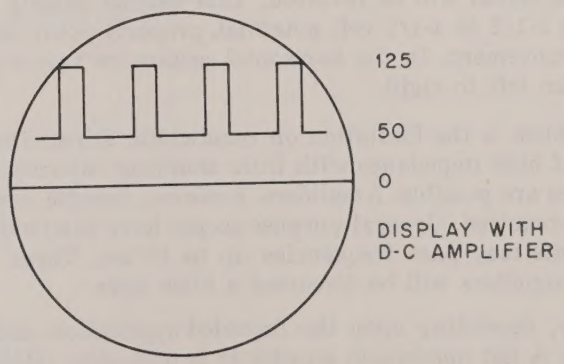


Fig. 9

Unfortunately, if the signal has a high d-c base component, the amplifier gain may have to be lowered, or the vertical centering changed, to keep the pattern from being deflected completely off the face of the scope. As depicted in Fig. 10, this may result in a pattern too small for usefulness. D-c amplifiers usually have an input capacitor or a capacitor-coupled pre-amplifier which may be switched in for a-c operation.

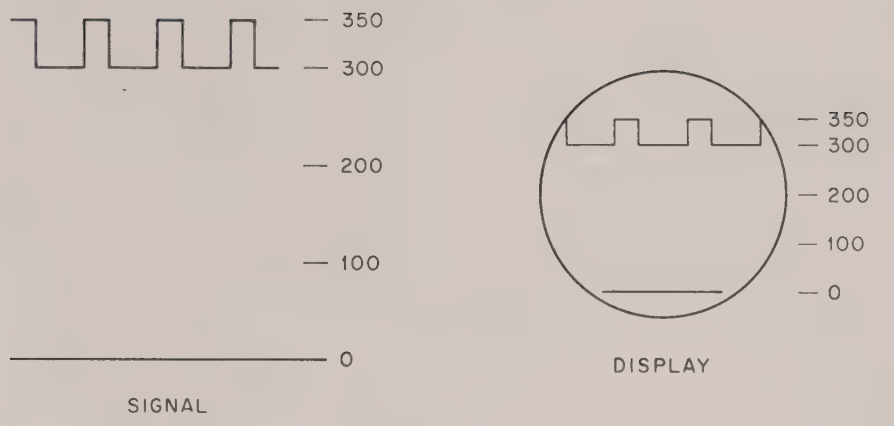


Fig. 10

Attenuators

It should be apparent that some form of gain control will be required if our scope is to be universal in its application. If our CR tube has a sensitivity of 20 volts per inch, we would normally limit our display to 3 or 4 inches of the 5 inch face; therefore, the amplifier would have a maximum output of 60 to 80 volts. If we have a 0.01 volt maximum sensitivity, the amplifier gain would be $\frac{20}{.01}$ or 2000! Thus, a ten-volt signal would try for a 20,000 volt output!

Gain controls all serve to reduce the amplified signal but are designated in different ways. The simpler scopes have potentiometers in the grid of the first or second (if provided) amplifier stages and are simply marked VERT GAIN or HOR GAIN. The better scopes have two gain controls — coarse and fine. The coarse control is generally a step-type attenuator while the fine control is usually a continuous potentiometer. The attenuators are "frequency-compensated" in order that they will not affect the frequency response and are usually adjusted by viewing a square wave with components up to the highest frequency of the bandpass, e.g., a 400-kc square wave should check up to 4 mc. Typical displays are shown in Fig. 11.

Fig. 11

In Fig. 12 we have shown a three-step attenuator with a 10-times multiplication per step.

In other words, step three gives only 1/100 the deflection that step one does for the same input signal. Another way of saying it is, that if step one has a deflection sensitivity of 0.25 volt per inch, step three will have a sensitivity of 25. The fine control is arbitrarily calibrated 1-10 and would give any proportion of the input sensitivity, e.g., on step two: 0 to 2.5 volts per inch.

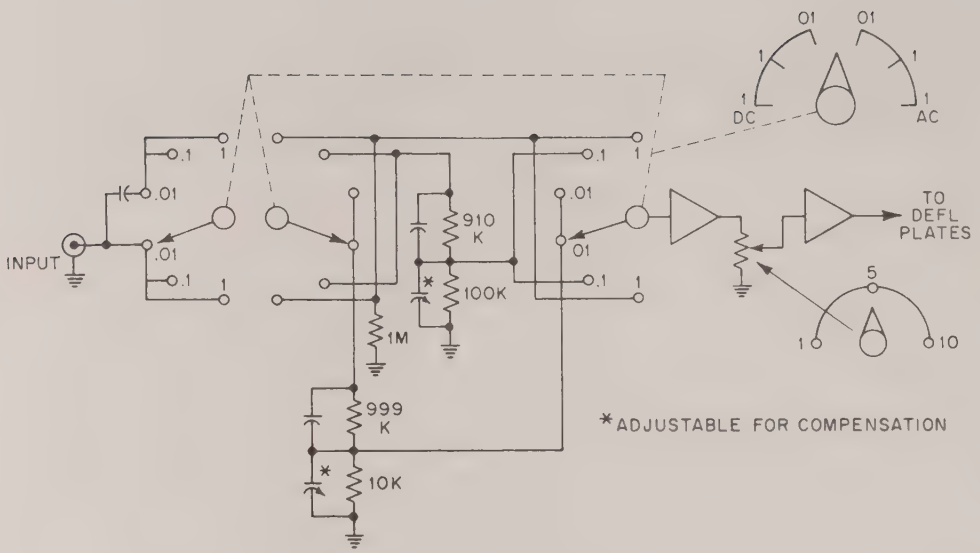


Fig. 12

The method of calibrating gain controls differs with the manufacturer. In our example each step is a multiple of 10 and the markings indicate the ratio of deflection for a given input. Thus for a given input signal the deflection on step 0.01 will be one tenth the deflection on step 0.1.

A common testroom oscilloscope is calibrated in terms of the peak-to-peak (or d-c) voltage necessary to give full scale deflection. It has steps of 0.1, 1, 10 and 100 for the main attenuator and steps of 1.0, 1.5, 2, 4 and 10 multiplication for the "fine" control. If we were to mark the top of the potentiometer, in Fig. 12, with a "1", then half way down would be "2" and three quarters would be "4", etc. For calibrations of this sort, the gain of the amplifiers must be of proper value and the scope mentioned has an internal gain adjustment.

A more common calibration, on the more expensive scopes, is in terms of volts (P-P) per centimeter of deflection. With this arrangement, the fine control is used to set the reference gain.

Synchronization

We have mentioned the need for a sweep generator to cause the beam to traverse the tube face, horizontally, and have shown that ideally this is a saw-tooth signal with a steep "rise-time" to reduce fly-back time.

Sweep generators may be of two types: free-running or start-stop. The first is sometimes designated as AUTOMATIC and the second as TRIGGERED. Let's first discuss the free-running sweep generator. This is a device which will continue to produce a repetitive saw-tooth signal with a repetition rate determined by adjustable elements. In order to obtain a stable pattern, the signal being examined must be swept by a saw-tooth of the same frequency. Fig. 13 shows what happens when the sweep duration is 1-1/4 times the signal.

In three sweeps, it is apparent, that three different patterns result. This would be a confusing display! To avoid this we use synchronization. The sweep generator is adjusted to operate at a slightly lower rate than the incoming signal. Then a small sample of signal voltage is amplified

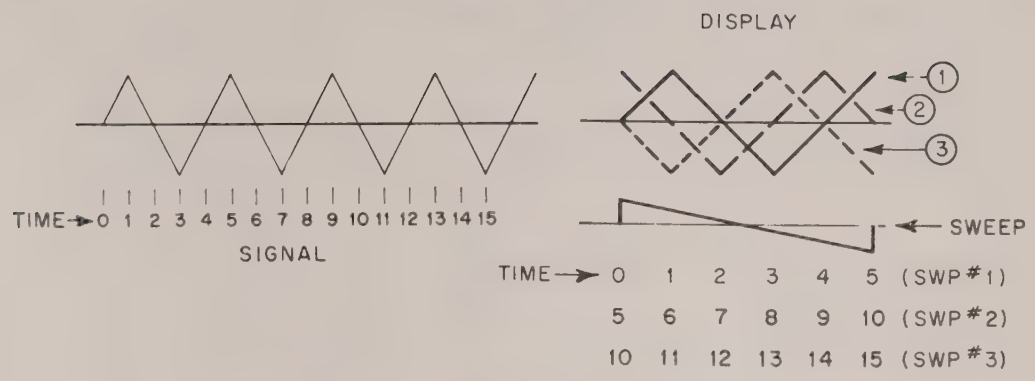


Fig. 13

and used to "trigger" or precipitate the return trace prematurely. Thus the sweep and signal are kept in step. Most scopes permit triggering of the sweep on either positive or negative signals. Whichever is used the pattern will remain the same, regardless of the signal phase, since the sweep is always started with respect to an *amplitude* rather than with respect to a *time*. Fig. 14 shows the display for signals of different phase when internal sync is used.

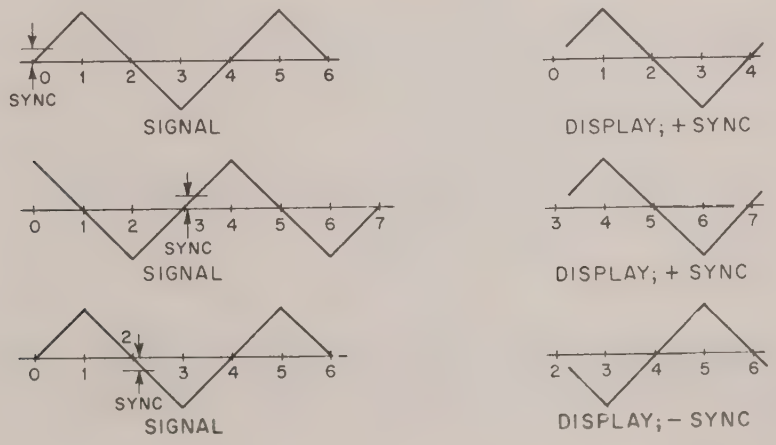


Fig. 14

If it is desired to compare two signals, with respect to phase, it is necessary to use an external sync signal and compare each display against the external timing. It is also possible to use *one* of the two signals to provide the sync voltage while displaying *either* one. The sync input can generally be selected by a switch with three positions: (1) Internal sync taken from the vertical amplifier for general display; (2) External sync taken from a binding post which may be connected to an external timing circuit for phase comparisons and; (3) Line or 60 cycle sync which is commonly used for 60 cycle "swept" displays. This is indicated in the block diagram of Fig. 15.

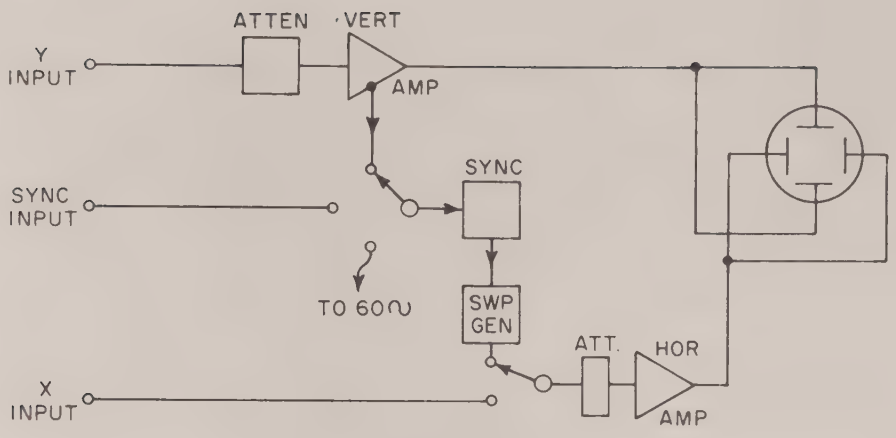


Fig. 15

Triggered Sweep

This type of sweep generator is useful for two situations — transient observation and sweep expansion. When triggered, the generator will complete one sweep and then stop, until triggered again. Thus a transient, or random, signal will always start the sweep and be displayed in the same place on the tube face. To assure the signal appearing, a delay is built into the vertical amplifier so the signal is not presented until after the trace has started. This is diagrammed in Fig. 16.

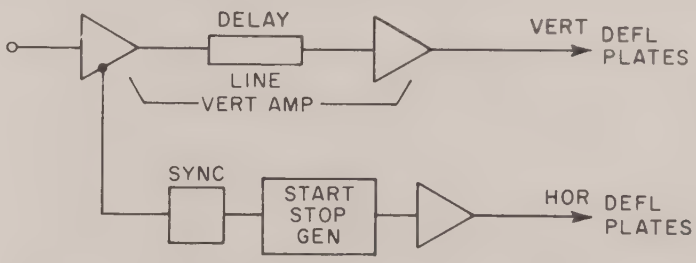


Fig. 16

By selecting the rate of the sweep, the signal may be expanded on the scope since the sweep duration (which still completes a full trace) may be made short with respect to the signal duration. This is illustrated in Fig. 17.

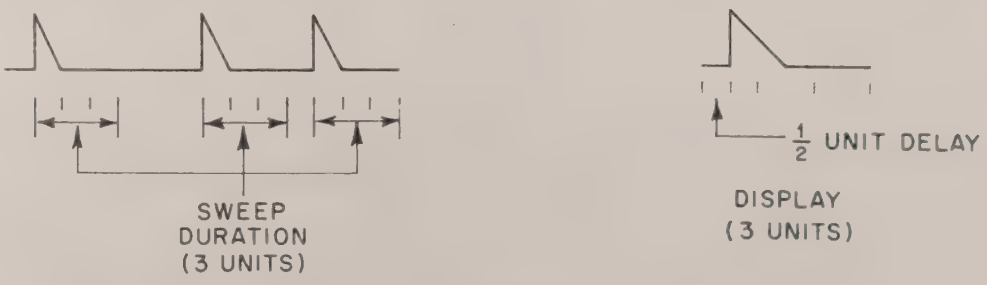


Fig. 17

A triggered sweep is particularly useful when examining the first part of a recurring signal, as can be seen in Fig. 18.

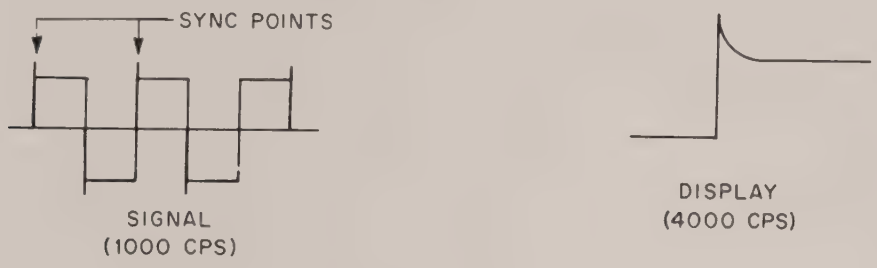


Fig. 18

If the vertical amplifier has means of adjusting the delay, other portions of the signal may be observed. In Fig. 18, the sweep completes during the first quarter cycle of signal and then waits to be triggered at the start of the next cycle (+ sync). As in the free running generator, negative sync can also be used.

PART 3

Controls

We have discussed, so far, the things which make up an oscilloscope as well as their purpose and effect. Let's now review these to see what controls appear externally and how we use these controls. The block diagram on the next page does not represent any particular oscilloscope but incorporates most of the features already discussed. If an oscilloscope is available, the following procedures can be tried out as we discuss them.

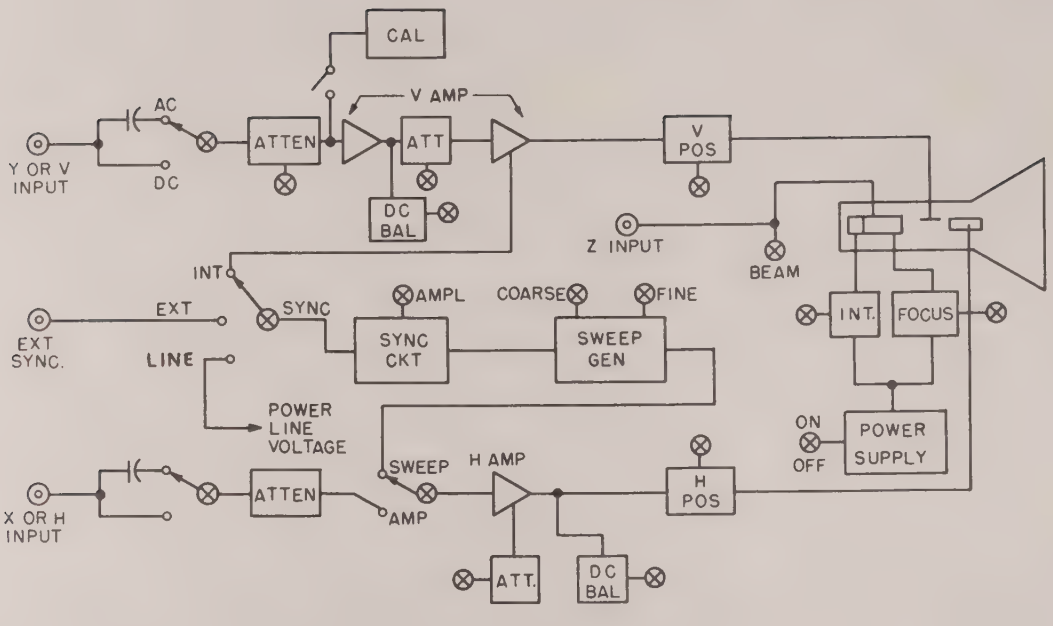
Examine the oscilloscope and try to locate the controls associated with the block diagram in Fig. 19. To help, the face of a Dumont 304A is shown in Fig. 20.

First find the input vertical attenuator (VOLTS FULL SCALE) and set it to OFF; or maximum attenuation if no OFF position is provided. Do the same with the horizontal attenuator. Place the horizontal input selector in the HORIZONTAL INPUT or AMPLIFIER position. In the 304A, the X SELECTOR performs both functions. The purpose of these steps is to remove any possible deflection signal so that the stationary spot may be examined. Next place the position controls in mid-range. Do the same with the INTENSITY and FOCUS controls. Connect the oscilloscope to a source of ac supply and turn on the ac power switch. Most scopes have a pilot light which should indicate that the ac is now on.

After a short warm-up, a spot should be visible on the face of the tube. If not increase the intensity slowly, watching for a "bloom" of light near the edge of the tube. Slowly rotate the VERTICAL (Y) and HORIZONTAL (X) POSITION controls until the beam appears somewhere on the face of the tube. These controls adjust the fixed potentials on the deflection plates, to equalize them. Now center the spot with the POSITION controls.

Reduce the INTENSITY and adjust the FOCUS control until a sharp point of light is observed. Notice that these two controls interact. Do not leave a sharp, bright, stationary spot on the screen very long as it will burn the phospor and leave a brown spot. Reduce the INTENSITY until the spot can barely be seen. The FOCUS and INTENSITY controls adjust the beam current and the potentials on the electrostatic lens in the CR tube's electron gun.

Set the SWEEP RANGE to 50 to 250 cycles or to 2 milli-seconds per centimeter, the FINE or VERNIER control to mid-range, and the horizontal selector to RECURRING or AC AUTOMATIC sweep. Set the horizontal gain to mid-range (AC or DC, if selectable). Advance the INTENSITY



OSCILLOSCOPE BLOCK DIAGRAM

Fig. 19

and refocus until a sharp, horizontal line appears. The horizontal gain may now be adjusted until the line is about four inches or ten centimeters long. Observe from the sketches (Figs. 19 & 20) how these adjustments have applied a low frequency saw tooth to the horizontal deflection plates and adjusted the deflection voltage.

Now that we have a line, how do we get a pattern? Without changing the horizontal controls, let's set the vertical input for ac operation and place the input attenuator at 10 volts full scale or at 1 volt/cm. If we now grasp the bare vertical input terminal with one hand, we should see disturbance of the horizontal line. Still holding the terminal, adjust the vertical attenuator and fine control until the vertical deflection covers abouts half the tube face. This deflection is produced by stray ac fields, from house wiring, which are capacitively coupled by the body to the high gain scope input.

With the SYNC control at zero, slowly adjust the SWEEP VERNIER or SWEEP FREQUENCY FINE control until a sine wave type pattern appears and is nearly stationary. Now slowly adjust the SYNC AMPLITUDE control in a positive direction until the pattern "locks in" or becomes stable. (The sync selector must be in the INTERNAL position.) Now adjust the FINE FREQUENCY control until about three cycles are displayed. This control adjusts the sweep repetition rate while the sync adjustment determines the amount of voltage used to pull the sweep generator into step.

Now reverse the SYNC control to the same degree of negative sync. The pattern should now reverse and where the first half cycle was probably a positive or upward going half cycle, it should now be a negative or downward going pattern. In other words, the sweep generator is now locked to a negative amplitude rather than a positive amplitude.

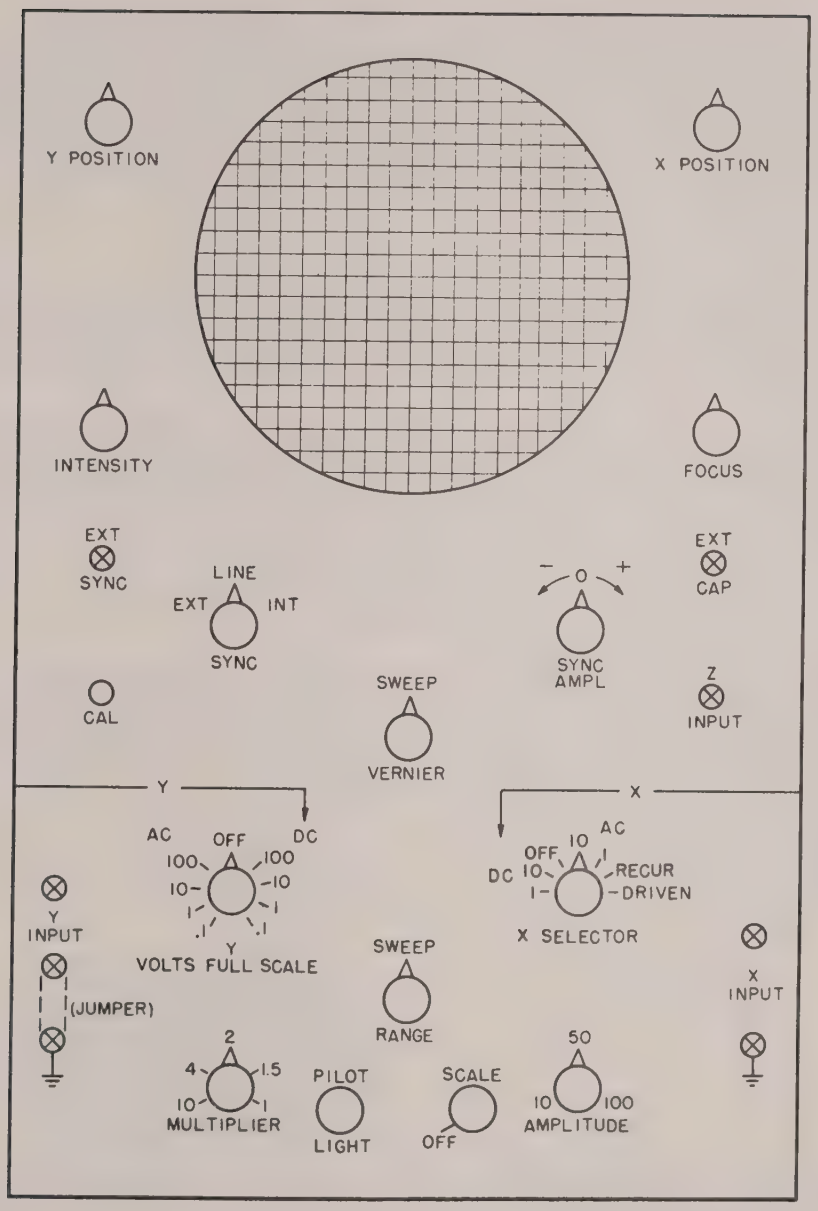


Fig. 20

We have now seen how the usual controls on an oscilloscope are used to present a display. These should be related to the block diagram (Fig. 19) and our previous discussion. Think about the operations performed. For example, our pattern is one of 60 cycle "pick up." With three cycles displayed, what is the sweep rate? Since it takes the time of three cycles to complete one sweep, the sweep duration must be 3 times 1/60, or 1/20 of a second — or a sweep repetition of 20 times per second.

As previously pointed out, all amplifier-type scopes must have means of adjusting focus, brightness, repetition rate, sync, vertical gain, horizontal gain and amplifier inputs. The location and designation of these controls will differ; however by examination and experiment in the way just outlined, these can be identified. Some scopes will be more precisely calibrated than others and thus permit additional, direct measurements. The manual furnished with the instrument will help identify these. Now that we know something about the mechanics of our instrument, let's review some of the things we can do with it.

Voltage Measurements

We know that the beam deflection is directly proportional to the voltage applied to the deflection plates. We should therefore be able to use the scope as a voltmeter. Since there is amplification between the input and the deflection plates, we must first calibrate the amplifier and this may be done in several ways.

If the oscilloscope has no internal calibrating means a separate signal source will be necessary as well as a means of measuring it. First, remember that conventional voltmeters are calibrated in terms of a particular duty cycle (or wave shape). Most ac voltmeters are calibrated in terms of RMS, sine wave and will read correctly on sine wave only. Since a scope displays the entire cycle visually, it is easier to look at the "peak-to-peak" voltage and apply this to any wave form. Peak-to-peak refers to the amplitude between the maximum positive and maximum negative voltage. Let's see how to make use of this with a scope which does not have d-c amplifiers. These require a "d-c balance" which will be discussed later.

If an ac test voltage is not provided on the scope, a separate source will be required. A 6.3-volt filament transformer will be satisfactory. With the vertical attenuator set at 5 volts/cm or 10 volts full scale, connect the secondary of the transformer to the vertical input and adjust for a pattern of two or three cycles, covering about 4 inches of the screen.

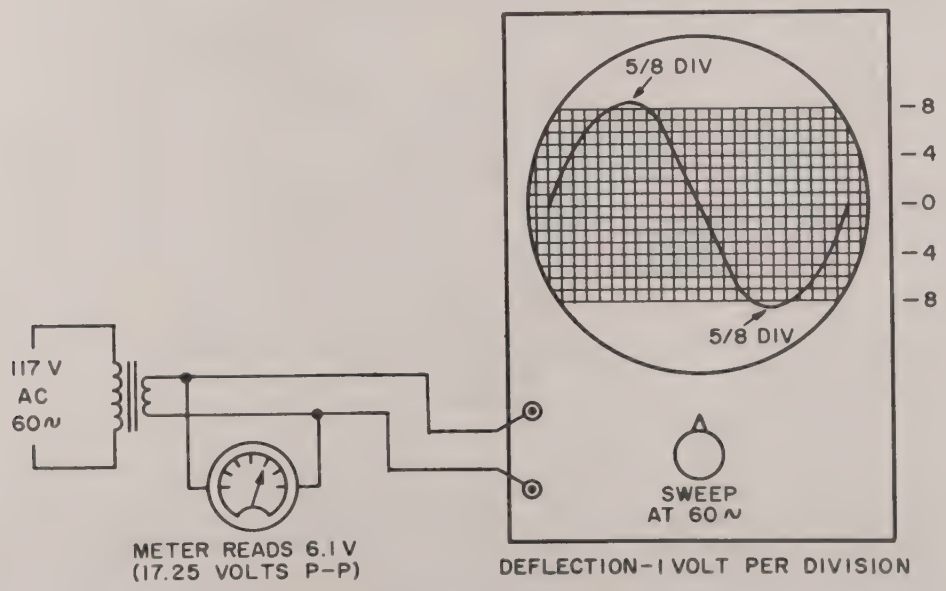


Fig. 21

Now, with an ac voltmeter, measure the input voltage. Let's assume the meter reads 6.1 volts. This is 0.707 of the peak voltage (RMS). The peak voltage is then 1.414 times 6.1 and the peak-to-peak voltage is then 2.828 times 6.1 or 17.25 volts. Now let's adjust the vertical fine gain control until the vertical deflection covers exactly 17.25 divisions on the screen. Our scope is now calibrated to one volt per division as shown in Fig. 21. We can now remove the reference signal and connect an unknown signal to the scope. If we *do not* touch the fine gain control, the scope will read directly. Suppose we are using the 304-A and the unknown signal goes off scale. We shift the attenuator from 10 to 100 volts full scale and the pattern now shows 20 divisions. The input voltage is then 20x10 or 200 volts. (20 divisions times the 10 multiplication of the attenuator.) Likewise, for an 8 division deflection on step 1 of the attenuator, the signal would be 0.8 volts. Almost any voltage may be measured this way by using a suitable calibration providing the breakdown voltage of the input capacitor is not exceeded!

If the wave shape is irregular, and peaks are difficult to determine, a more accurate measurement can be obtained by reducing the horizontal gain to zero and reading the length of the resulting vertical line. Fig. 22 shows the two displays for this situation.

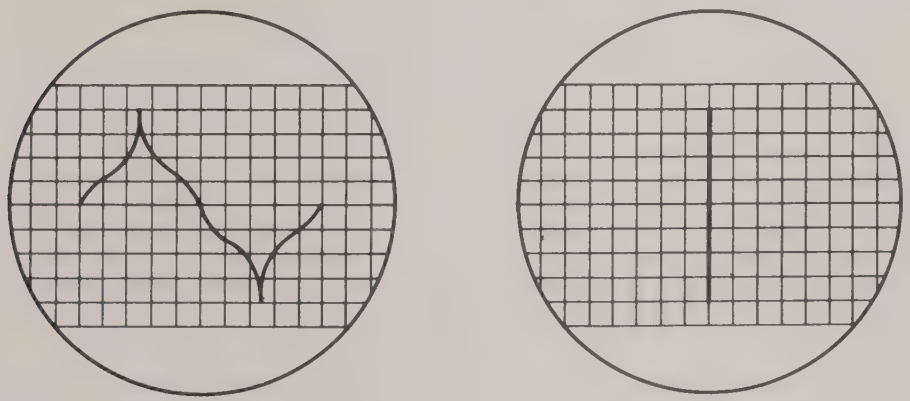


Fig. 22

When using a scope calibrated in volts per centimeter, the procedure is quite similar. With the reference signal applied (17.25 in our case) we should adjust the fine gain control until the deflection covers 3.45 mc. Then each cm represents 5 volts. If we now shift the attenuator to 2 volts/cm, without any other change, the deflection should cover about 8.62-1/2 cm. In other words, if the calibration is unchanged, the deflection, in cm, multiplied by the volts/cm setting of the attenuator will give the actual input voltage.

Measurement of d-c voltages can be made in the same way, if a d-c scope is available. In this case, a "pattern" will not be presented. The beam will be deflected by the magnitude of the voltage and, if the horizontal sweep is operating, the horizontal trace will move up (or down) and stay there as long as the d-c voltage is applied. The distance the line is moved is the indication and represents the actual voltage since d-c, in this case, is the equivalent of peak-to-peak.

D-C Balance

A d-c amplifier is one which amplifies a d-c voltage and therefore has a direct connection throughout. Consequently, if an unbalance exists in the typical amplifier shown in Fig. 23, a d-c voltage could appear across the fine gain control potentiometer.

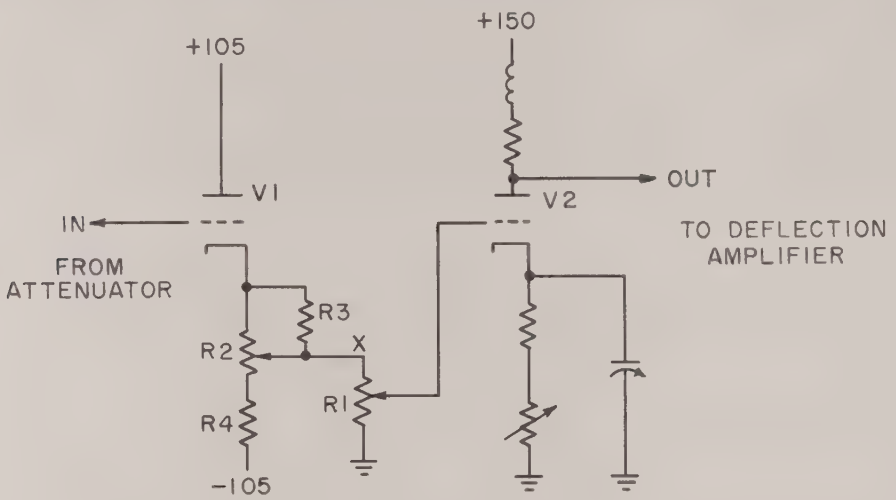


Fig. 23

In the Figure, we have shown a single ended amplifier, however the same problem exists in push-pull stages. The output from the preamplifier appears across the fine gain control R1. If the characteristic of tube V1 varies, the potential across R1 will not be zero with no-signal input. Then if R1 is varied, a deflection signal will be applied to the beam and it will assume a different position for each setting of the control. By adjusting R3, the IR drop across R2, R3 and R4 can be made equal to that across V1. The voltage at point X will then be zero.

In practice, R3 is adjusted so that there is no change (with no signal input) of the beam position for any setting of R1. The d-c balance control is usually a screwdriver adjustment on the face of the scope and should not be adjusted until the scope is fully warmed-up. It should then hold for long periods of time.

It is apparent that this adjustment will not affect wave shape, over normal ranges, but will be very critical in the accurate measurement of voltage amplitudes.

Calibrating Signals

Most of the better scopes have built in calibrating voltages. In one Plant used RCA scope, a variable voltage is provided with a meter calibrated in peak-to-peak volts. In another, a VR-tube controlled clipper is used to provide a 60 cycle square wave. In the Dumont 304A, a dual-diode clipper is used with an internal calibrating potentiometer for calibration. In a popular kit scope, the calibration is a d-c voltage taken from a VR-tube.

Several calibrators are also available, which will produce known voltage outputs. These may be connected to manually (or electronically) switch the vertical input from signal to calibration voltage. The calibration voltage may then be read from a scale on the calibrator when the two signals cause the same deflection.

It should be apparent that if we understand basic scope operation, calibration methods are limited only by our ingenuity. Remember, however, that voltage measurement with a scope is independent of wave shape; however, calibrating meters must be used with the wave shape for which they are calibrated.

Review

By now it should be apparent that all scopes have most controls in common. If we have tried out the procedures discussed here, we should have no trouble using most scopes. With each new instrument, first stop and examine the controls, their location and their designation. Then relate these to the block diagram in Fig. 19. As we discover more things to do with the scope, we will assume that you have mastered the process of presenting a stable display and will spend our time on interpreting these displays.

PART 4

Lissajous Patterns

Now that we know what an oscilloscope is, and how to operate it, we can explore some of its uses.

If we think back, we remember that the beam in our CR tube can be acted upon independently, by two separate forces — one in the horizontal direction and one in the vertical direction. If we apply sinewave signals to the two deflecting amplifiers, and these signals bear an integral relationship to each other, the result will be very definite patterns known as Lissajous figures.

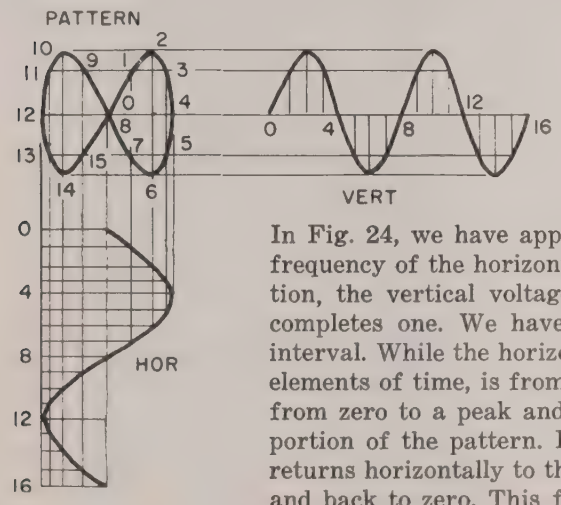


Fig. 24

In Fig. 24, we have applied a vertical deflecting signal having twice the frequency of the horizontal deflecting signal. By the terms of our assumption, the vertical voltage will complete two cycles while the horizontal completes one. We have arbitrarily assigned 16 units of time for this interval. While the horizontal movement of the beam, during the first four elements of time, is from the center to the right, the vertical movement is from zero to a peak and back to zero. This is shown as the upper right portion of the pattern. During the next four elements of time the beam returns horizontally to the center but moves vertically from zero to a peak and back to zero. This forms the right half of a "bow tie." In the same way the left half can be traced by following the numbered intervals. If we were to enclose the resulting pattern in an imaginary rectangle we would see that it would touch, or have points of tangency, at times 2 and 10 or 6 and 14 on the horizontal side and times 4 or 12 on the vertical side. This is of interest since it gives a means of frequency checking. If we divide the horizontal tangencies caused by the vertical signal, by the vertical tangencies caused by the horizontal signal, we immediately know the ratio of the two signals. In this case we have horizontal tangency at 2 and 10 (or 14 and 6) with vertical tangency at 4 (or 12) thus the ratio is 2 to 1 and we know the vertical frequency is twice the horizontal.

If we apply an unknown frequency to one set of plates and vary the frequency applied to the other set until a stable pattern results we can thus find the unknown.

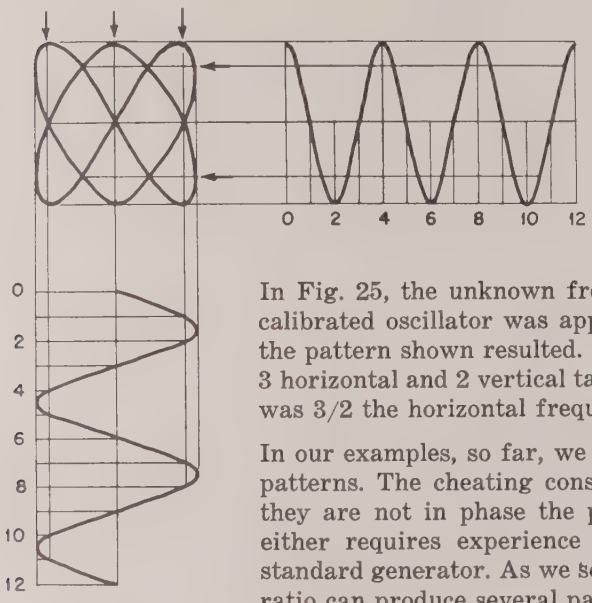


Fig. 25

In Fig. 25, the unknown frequency was applied to the vertical plates. A calibrated oscillator was applied to the horizontal plates and varied until the pattern shown resulted. The oscillator read 600 cycles. Since there are 3 horizontal and 2 vertical tangencies (shown by the arrows) the unknown was 3/2 the horizontal frequency, or 900 cycles.

In our examples, so far, we have cheated slightly in order to simplify the patterns. The cheating consisted of having both signals in phase. When they are not in phase the pattern is sometimes difficult to identify and either requires experience or experimentation in the variation of the standard generator. As we see in Fig. 26, two frequencies with a two to one ratio can produce several patterns. In the first case the "bow tie" becomes droopy as the vertical frequency lags the horizontal. As it lags more, the two halves become superimposed as shown in the second pattern. The arrows show that there are two horizontal tangencies but that one is on top of the other. With an even greater phase difference the pattern reverses.

The photo, Fig. 27, shows an actual scope presentation using 60 cycles and 120 cycles in phase. The next photo, Fig. 28 is an actual scope presentation of two out-of-phase signals having a 3 to 1 ratio.

Space does not permit showing the many varied and more complex patterns possible, however, the interpretation remains the same, regardless of the frequency ratio. It is suggested that the reader experiment in generating his own patterns and confirming the tangency ratio. With 60 cycles applied to the horizontal input and an audio generator applied to the vertical input ratios of as high as 10 to 1 are readily identified. If one signal is 60 cycles, what is the other signal in the following pattern? (See Fig. 29 on the next page.)

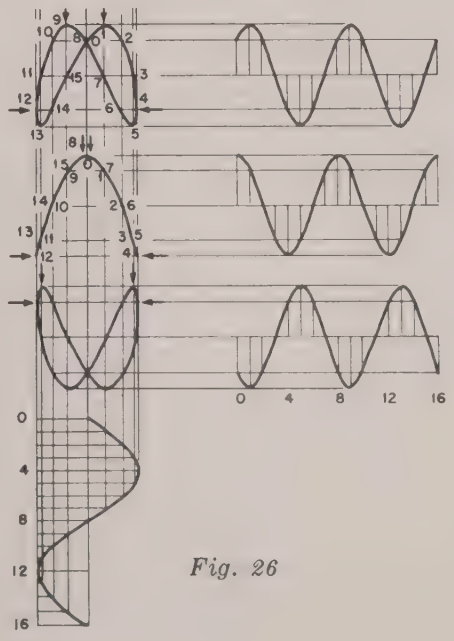


Fig. 26

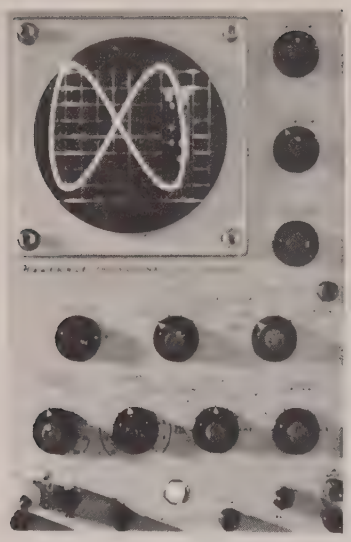


Fig. 27

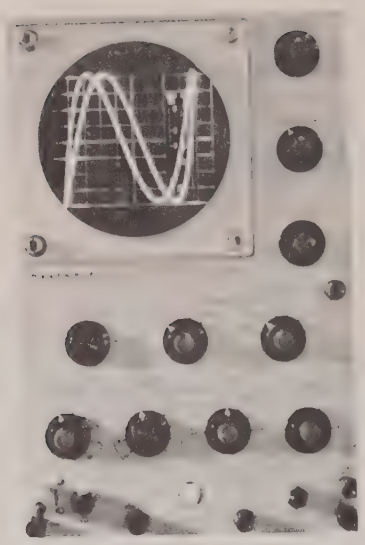


Fig. 28

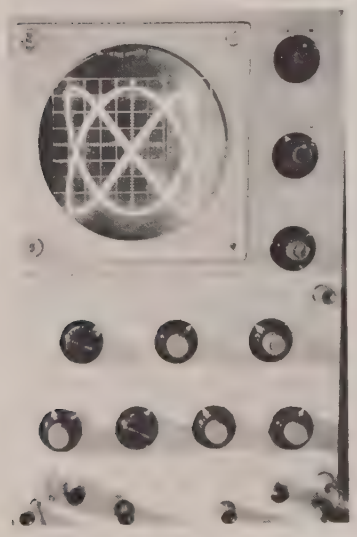


Fig. 29

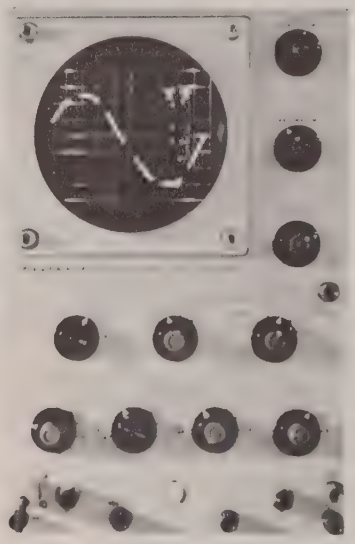


Fig. 30

Z-Axis Measurements

If the standard or known frequency is applied to the CR tube grid it will add to and subtract from the grid bias. Thus, as the known frequency goes in a positive direction the beam intensity increases, and as the known signal goes in a negative direction the brightness is decreased.

If a signal is now displayed, in a normal manner, it will appear to be made up of a "dashed" line in which each pair of light and dark spaces correspond to one cycle of the Z-axis signal. The light and dark spaces will not necessarily be equal since the beam cut-off will depend upon the Z-signal amplitude and the scope characteristics, as shown in Fig. 30.

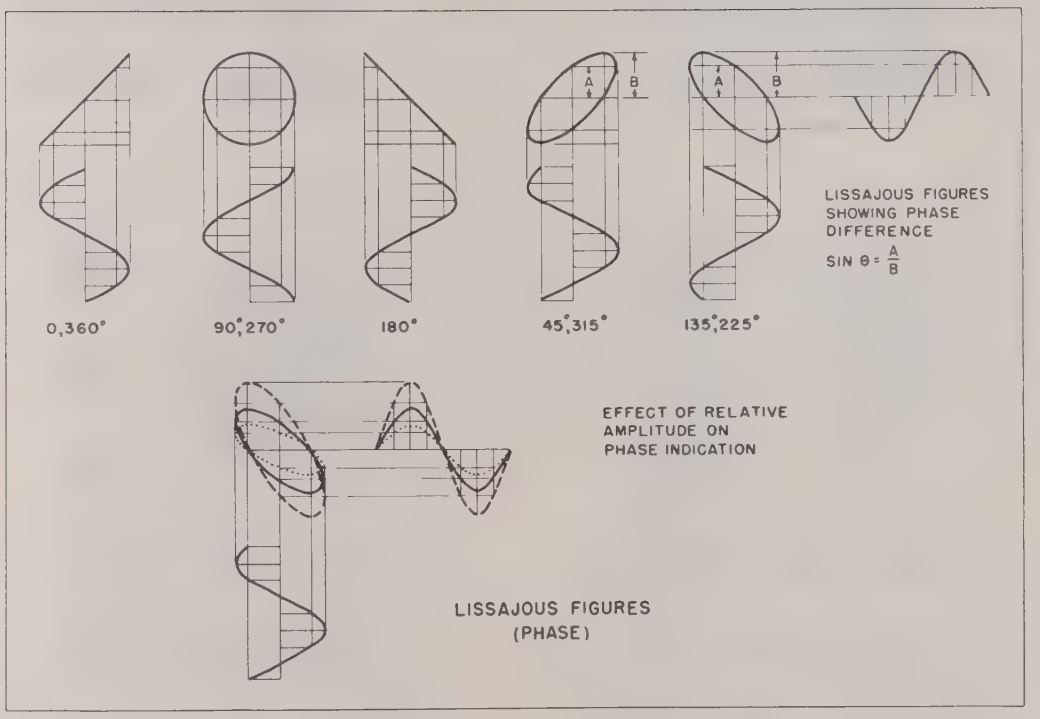

A
B
A
B
0,360°
90°,270°
180°
45°,315°
135°,225°
LISSAJOUS FIGURES
SHOWING PHASE
DIFFERENCE
SIN θ = A/B
EFFECT OF RELATIVE
AMPLITUDE ON
PHASE INDICATION
LISSAJOUS FIGURES
(PHASE)

Fig. 31

In the photograph the light to dark shows a ratio of about 2 to 1 for this reason. Note a dark space at the start of the trace and a bright one at the end to make a total of 6 pairs. The pattern therefore has a frequency of 1/6 of the "standard" frequency which in this case was 360 cycles.

Again we have demonstrated a method of measuring frequency by using the scope as a "comparator" between the unknown and a known frequency.

Time Base Measurements

Many of the more expensive scopes have the time base (horizontal sweep) accurately calibrated. The horizontal deflection is adjusted to cover exactly ten centimeters. The time base is then set to display one or two cycles. Let us assume we have displayed one cycle and the time base control is set at 0.2 milliseconds per centimeter and the multiplier reads 8.3. The total time is then 8.3 x 0.2 or 1.66ms per centimeter and the duration of the one cycle is then 10 times 1.66ms or 0.0166 seconds. This corresponds to 1/60 second for one cycle or a frequency of 60 cycles per second.

If a two-cycle signal were presented with the controls at 0.2 milliseconds per centimeter and the multiplier at 1, the time for one cycle would be 5 (1/2 of 10cm) times 0.2 or 1 millisecond. This is 1/1000 of a second and the signal would thus be 1000 cycles. This is illustrated in the photograph by the two center knobs in the bottom row. (Fig. 32.)

Phase Measurements

In observing our Lissajous patterns we noticed the effect of phase. If the two signals are of the same frequency, quite accurate checks of phase can be made with an oscilloscope. The development of the patterns is shown in Fig. 31. At 0, 90, 180, 270 and 360 degrees very definite and easily identified patterns are obtained if the amplitudes of the two signals are kept equal. At other differences the ellipse can be measured and the phase relationship determined from a slide rule or a set of trigonometry tables. The patterns also show the error introduced if the amplitudes are not equal. The actual appearance on an oscilloscope is shown in Figs. 33, 34, and 35.

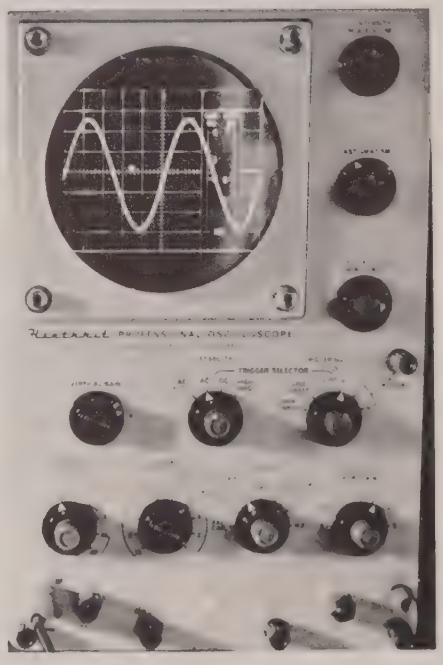


Fig. 32

The lines are not always straight or smooth and sometimes do not completely overlap.

In the case of the two photos at or near 180 degrees (Figs. 34 and 35), one of the signals had some harmonic content and did not exactly match the other.

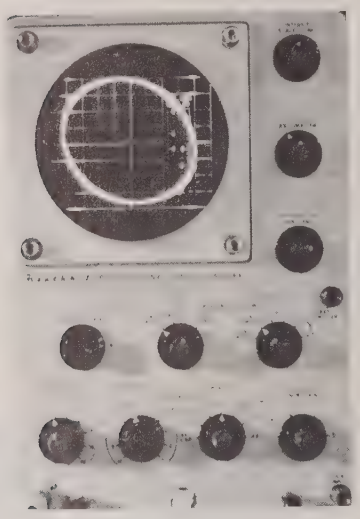


Fig. 33

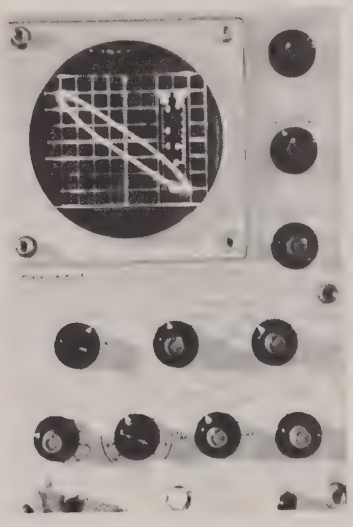


Fig. 34

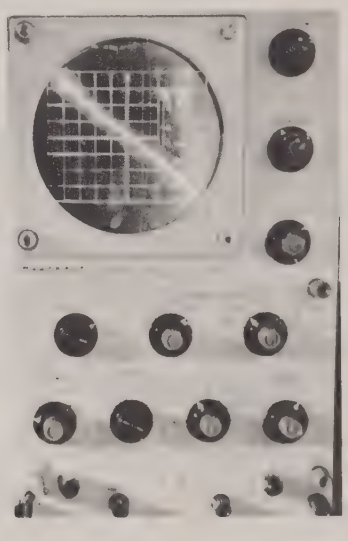


Fig. 35

Occasionally a complete wave shape is displayed against the linear sweep. A second wave is next displayed and its displacement noted. This can then be interpreted in percent of a cycle or in degrees to determine the phase relationship of one to the other. In doing this a particular caution must be observed. If internal sync is used both patterns will look the same since the sweep will always start at the same voltage. The sync must be obtained externally from one of the two signals to be compared. The sync will then always start at the same voltage *and time* and one of the signals will be displaced in proportion to its time displacement with respect to the sync voltage. A review of the sync principles discussed in Part 2 should clarify this.

PART 5

Wave Shape Observation

Probably the most common use of an oscilloscope is the examination of wave shapes. This may be for the purpose of checking the response of an amplifier; locating trouble, such as distortion; determining the effect of circuit changes; checking the shaping of waves, as in TV sweep circuits; analysis of transmission, as at a TOC; and many similar problems.

Before a wave shape may be analyzed, however, certain conditions must be satisfied. The first requirement, obviously, is that we understand the circuit or equipment we are checking well enough to know the wave shape we are expecting to see. If we do not know what the shape should be we certainly cannot analyze the one we see.

A second requirement is that we know the characteristics of the oscilloscope we are using. If the capability of the amplifiers, in the scope, are exceeded a distorted pattern will be displayed by the CR tube. Its beam goes where directed and it cannot differentiate between distortions at the input and output of its own amplifiers.

A problem with older scopes is a too sharp cutoff in the frequency response of the vertical amplifier. When a signal, such as a spike or a square wave, containing frequencies in excess of the band pass is applied "ringing" will occur. This will appear as one or more spikes following the original spike or as spikes and ripples on the leading edges of square waves.

For general use, however, we are concerned with the basic band pass and in modern scopes this band pass usually has a slow "roll off" rather than a sharp cut off. How does this band pass affect us?

Suppose we want to compare two signals which should have the same amplitude. Let's assume these are 10,000 cycles and 700,000 cycles. Let's further assume that we are using a scope with a nominal band pass of 1.0 megacycle. If the vertical gain controls are adjusted and then left alone, either signal will give the same amplitude of deflection unless the signals, through some error, are not of the same magnitude. This of course was what we wanted to check. Now suppose we were to make the same measurements with a scope having a nominal band pass of 0.5 megacycles. Now, even though both input signals are identical in amplitude, the 700,000 cycle signal will show a marked decrease in deflection and an erroneous indication will be obtained.

Since a square wave is a composite of a fundamental and at least ten significant odd harmonics it is used, quite frequently, to check the frequency response of audio amplifiers. The photos of Figs. 36-38 show what happens when the oscilloscope response is inadequate.

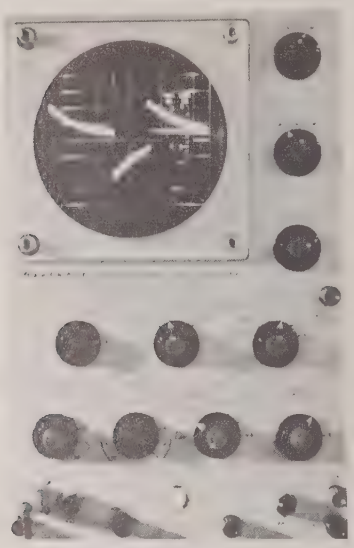


Fig. 36

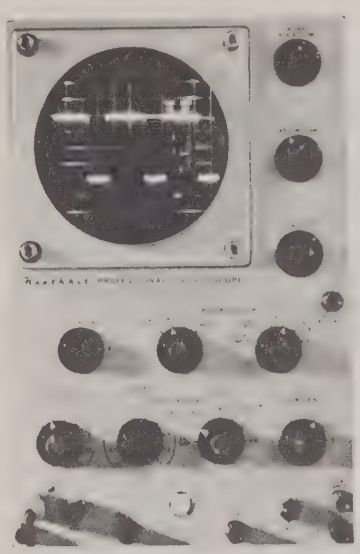


Fig. 37

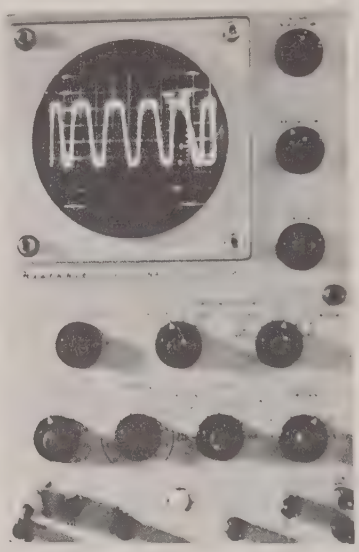


Fig. 38

The center pattern shows normal response. The "rise time" is very fast and therefore the vertical sides of the square wave do not show. The beam moves so rapidly that the screen is not illuminated. The photo on the right shows slope or a "slow rise time" on the sides of the square wave and rounding of the corners. This indicates loss of high frequency amplification and thus attenuation of the higher harmonics. In the lefthand photo the low frequency response is low. Here the capacitive coupling is apparently too little and integration is occurring. (Due to the broad band pass of the scope available for photographs the patterns displayed had to be simulated.)

It is therefore apparent that the frequency response of the scope amplifiers must be greater than the band of frequencies to be examined if the scope is not to introduce distortions and change either the amplitude or shape of the applied signal.

Another problem experienced with the less expensive scopes is overloading of the input amplifier, resulting in clipping. This is particularly true with cathode follower inputs. If a sine wave input signal shows one peak, or both, flattened or "squared-off" introduce attenuation between it and the scope. If the pattern then assumes the expected shape, you will know that the scope was causing the distortion. Where the attenuator is placed ahead of the first amplifier, in the scope, this should not be a problem.

Electronic Switch

In checking the response of a device, it is often desirable to look at both the input and output wave shapes. In this way phase displacement, wave shape changes, etc., can be confirmed. If both can be observed simultaneously the comparison is simplified. Certain, specialized, scopes accomplish this with two or more guns in the same CR tube envelope. A more inexpensive way is to use a switch which will rapidly transfer from one input to the other. If the switching rate is fast enough the persistence of the screen and the persistence of vision will give the illusion of two simultaneous wave shapes.

To obtain high enough switching speeds, each of two amplifiers can be alternately biased to cut-off. This can be done with a multi-vibrator quite readily. If the amplifier outputs are paralleled the two separate inputs will alternately appear in the output at a rate determined by the multi-vibrator. This is called an electronic switch.

Some oscilloscopes, such as the Tektronix, have plug-in preamplifiers with a built-in switch. Separate switches are also readily available. These have separate gain controls for each of the two flat amplifiers. They usually have controls for varying the switching speed and a control for adjusting the relative voltage level of the two output tubes, in order to change the relative vertical position of the two signals on the scope. In Figs. 39, 40 below, the lefthand patterns have been displaced, while the righthand patterns have been superimposed.

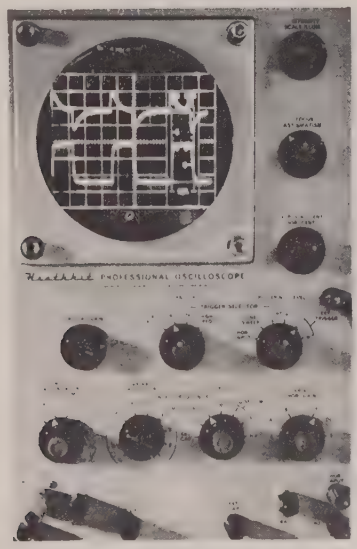


Fig. 39

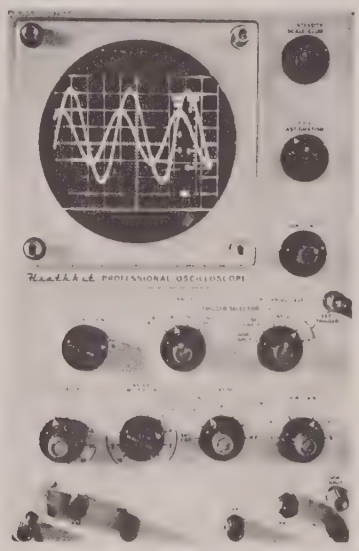


Fig. 40

The lefthand patterns indicate the effect of low frequency distortion, the lower being the input signal and the upper being the output signal. The righthand patterns show phase shift. The larger is the input signal and the smaller is the output signal. Both sets of patterns were produced by improper R-C coupling.

When using an electronic switch it is necessary to use external sync. If internal sync is used the poor sweep circuit becomes dizzy trying to decide which signal to sync on and an unstable pattern results. In the photos, the input signal was used to furnish sync.

Sweep Linearity

In many scopes the beam does not progress across the tube face at a constant speed. This is particularly evident at low sweep rates and is due to the fact that the sweep is generated by the charging of a capacitor through a resistor. The sketch in Fig. 41 shows how this occurs. The indication, as the diagram shows, is a compression of the right side of the pattern as the beam slows down.

The effect upon a pattern can be minimized by displaying 3 or 4 cycles and then with the horizontal gain and position controls adjust for a one-cycle presentation; e.g., the second cycle of a 4-cycle display. The better scopes seldom show this effect today.

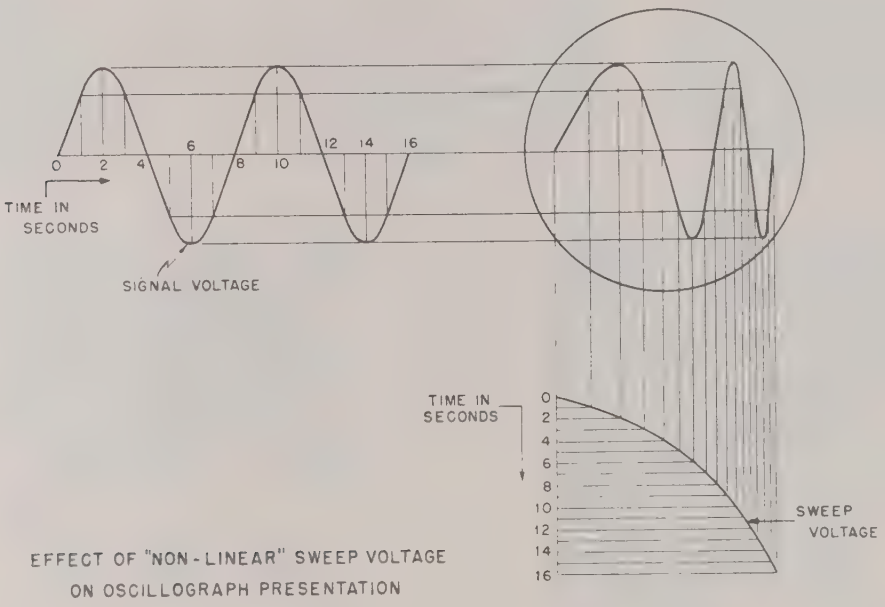


Fig. 41

Probes

Although oscilloscopes have a high impedance input, it is still a finite value and can affect the circuit being measured thus distorting the displayed pattern. The instrument used in the photos has a 1,000 cycle input of 3.2 megohms or 3.6 megohms shunted by a 28 mmf capacitance. The use of connecting leads could increase this shunt capacitance appreciably. Such a capacitance in a high frequency circuit could cause an appreciable change in characteristics and therefore in the wave shape.

To isolate the scope a "probe" is used. Fig. 42 is typical of such a probe.

The values have been chosen so that 1/10 of the signal is across R2 and 9/10 across R1 when the switch is in the X10 position. C1 forms part of a second voltage divider in which the other leg of the divider consists of the capacitance placed across R2 by the cable and scope. When C1 is properly adjusted 9/10 of the signal will appear across C1 and 1/10 across the capacity of the shielded cable. Thus there is a 10 to 1 signal reduction however the 100mmf or more of cable and scope capacitance has been reduced by placing C1 in series, across the load. The input impedance of the probe is 2.4 megohms shunted by less than 20mmf in the X10 position. In the normal, or direct position the input will be 2.4 megohms shunted by 100mmf or more when the usual coaxial cable is used.

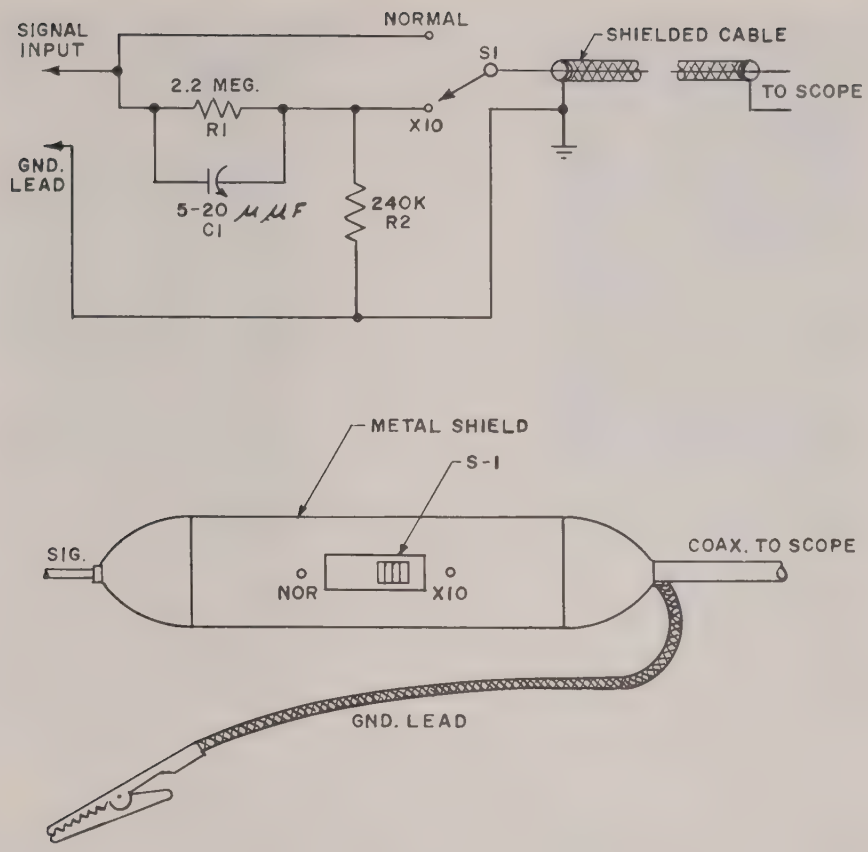


Fig. 42

Input Leads

We have indicated the need of a "low capacitance" probe for some situations because of the 100mmf or so of cable capacitance. You might well say — "Let's eliminate the capacitance by using short single wires, well separated." True, this would materially reduce the capacitance but would introduce another distortion.

Remember, we got our first pattern by simply grasping the input terminal? Scopes are generally used in areas with much AC wiring which is generating appreciable magnetic and electrostatic fields. Furthermore the vertical amplifier is generally being operated at high gain for small signal observation. Unshielded leads will therefore introduce 60 cycle signals which will be superimposed on the pattern. This will appear as a thickening of the horizontal lines or as an undulation of the pattern or a shifting of portions of the pattern, in the vertical direction, depending upon the amount of pickup and the frequency of the signal being measured. In other words, the scope will present the instantaneous sum of the two signals. Shielded leads should always be used to avoid this condition.

The photo on the left (Fig. 43) shows a signal of about 40,000 cycles using shielded leads. The photo on the right (Fig. 44) shows the same pattern with 60 cycle pickup when the leads are unshielded.

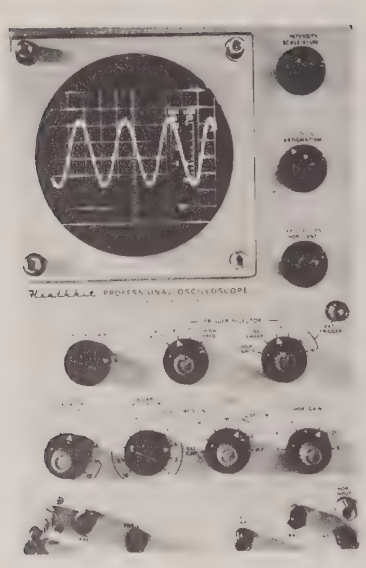


Fig. 43

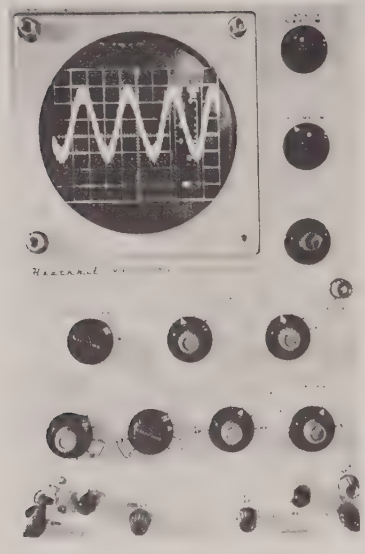


Fig. 44

Triggered Sweep

The wave shape examination discussed so far can be done with a synchronized "free-running" or recurring sweep. In other words the beam continues to sweep across the tube face at a constant rate, whether signal is present or not, determined by the panel control settings.

The better scopes also have provision for "triggered" or "start-stop" sweeps. In this arrangement the beam is swept across the tube face once upon being triggered and then waits for the next triggering pulse.

When a signal is being observed, which is transient in nature, it appears at irregular intervals. Thus, when using a free-running sweep, the signal will appear at random across the trace, depending upon the time in the sweep at which it occurs. Thus several patterns, with reduced brightness (since they are not over-traced) will be displayed. Moreover the patterns may overlap or be partially superimposed.

If a start-stop sweep is used a transient display will appear normal, since the sweep only occurs when the signal appears. Since the signal triggers the sweep, it would appear at the left of the trace and the part of the signal, up to the amplitude required for triggering, would not be displayed. To avoid this the signal is delayed in time, before reaching the CR tube by the use of electrical delay lines. Thus at a predetermined time after the signal triggers the sweep, it is presented to the CR tube deflection plates. The presentation then appears an appreciable time after the start of the sweep.

On recurring signals, it may be desirable to examine a small portion of the signal. This can be done, within limits, by increasing the horizontal gain and "expanding" the trace. The position control is used to select the desired part of the trace. Such displays are limited by the available gain and position control. In some scopes this increase in gain is accomplished in discrete steps of a "magnifier" control. Thus a 5 times magnification would mean a 5 times increase in gain and deflection. This factor would also need to be applied to the time base computations since only one fifth of the pattern would be under observation.

A simpler method of expansion is to use a triggered sweep and a higher sweep rate. Thus the entire sweep occurs, across the face of the CR tube, during a small portion of one cycle of the signal and that portion will be spread over the entire tube face.

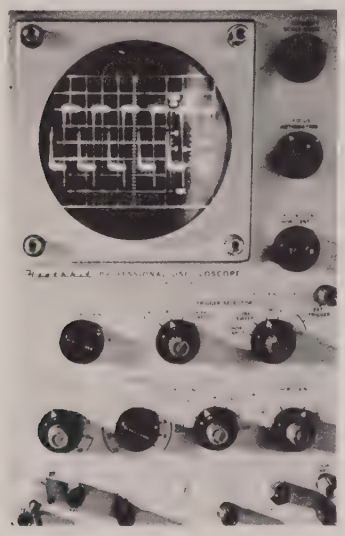


Fig. 45

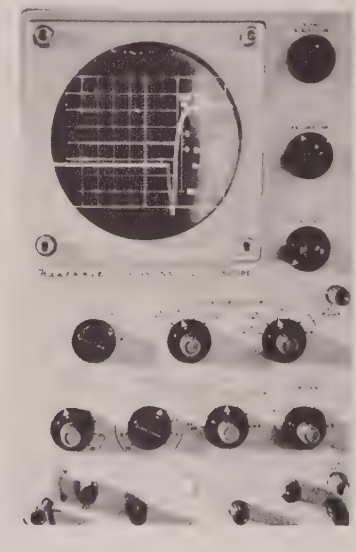


Fig. 46

In the photo at the left (Fig. 45) a square wave is displayed which has a sharp spike on the right of each negative half cycle. Since the spike occurs in an extremely small fraction of the time of one sweep it appears as a fine "whisker", so fine that it is difficult to reproduce. The photo at the right (Fig. 46) shows the spike only and was obtained by using a much higher, triggered, sweep rate and adding some sweep expansion.

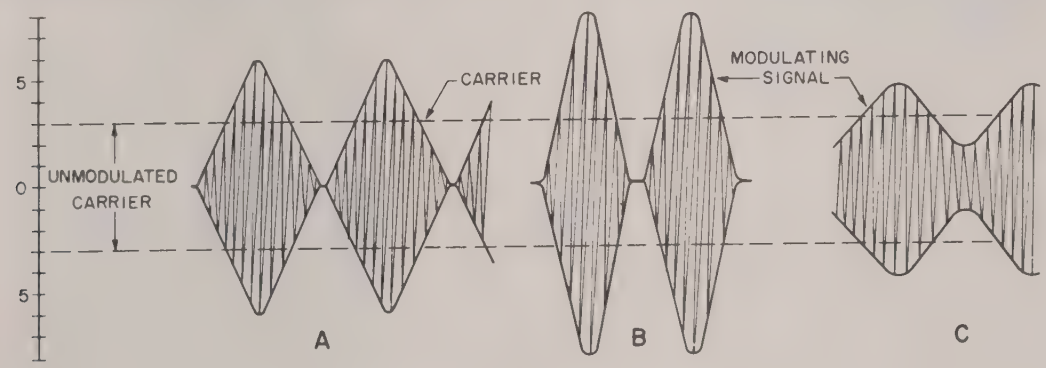
Summary

In an article of this type, only a limited discussion of wave shape observation can be given. We hope we have indicated some of the cautions as well as the flexibility inherent in most oscilloscopes. The illustrations cited should stimulate many more applications.

PART 6

Amplitude Modulation

In amplitude modulation systems, a "carrier" is varied in amplitude by the modulating signal. For most efficient operation, the carrier should be varied as much as possible without distortion. The unit for measuring this is the "percent" of modulation.



MODULATION ENVELOPES

Fig. 47

In Fig. 47A, a sine-type frequency has modulated a carrier 100%. The carrier of 6 units amplitude has been varied between 0 and 12 or changed by 100% in a positive and a negative direction. In Fig. 47B, the modulation exceeds 100% however distortion results due to squaring of the envelope when the carrier can not become less than zero. In Fig. 47C the carrier is increased by 1/2 and decreased by 1/2 (1-1/2 units on a 3 unit carrier) and the modulation is 50%. This can be computed by dividing the difference between peak and valley amplitudes by the sum and multiplying by 100, e.g. $\frac{4\text{-}1/2 - 1\text{-}1/2}{4\text{-}1/2 + 1\text{-}1/2} \times 100 = 3/6 \times 100 = 50\%$. To adjust a modulating system some means of measuring percent modulation is necessary. A meter and rectifier circuit can be used when calibrated against the unmodulated carrier, however an oscilloscope is of more use since it gives a visual indication of wave shape as well as percent modulation.

Modulation Envelope Display

As previously pointed out, the beam of a CR tube can be deflected at a rate approaching the transit time of the electron. It is therefore a voltmeter without frequency limitation at ordinary frequencies.

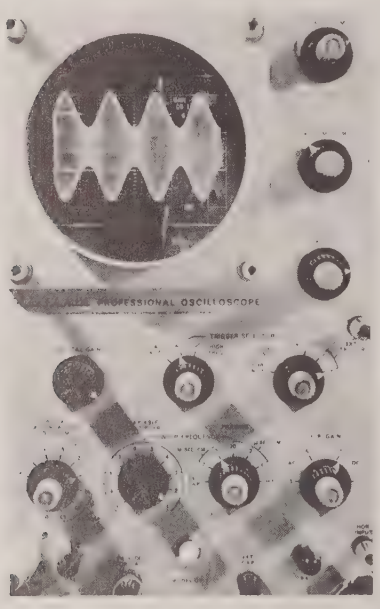


Fig. 48

In Fig. 48 a 4.0 mc signal, modulated with a 1000 cycle signal, has been applied to the vertical plates of the CRO. The internal sweep has been adjusted to display several cycles at a 1000 cycle rate. At approximately a 260 cycle sweep rate, the 4.0 mc signal is changing so rapidly that the vertical traces are adjacent to each other and the pattern appears to be a solid mass of light. This we can see, is a duplication of Fig. 47. Using the earlier "formula" we find the % modulation to be about $\frac{3\text{-}1/2}{7\text{-}1/2} \times 100$ or 46-2/3%. The pattern was obtained by modulating a Heathkit LG-1 generator with an AG-10 audio generator at about 45%. The CRO was synced from the AG-10.

In addition to determining the percent modulation we can get a visual display of the "quality" of the modulation.

In Fig. 49, we see a case of improper operation of the modulation system resulting in an unsymmetrical envelope. This would be difficult to detect with other forms of measurement.

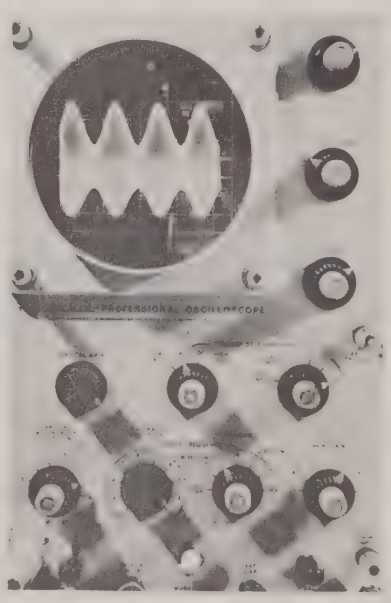


Fig. 49

Trapezoid Patterns

The previous patterns were made with a single modulating frequency, and with experience a fair estimation can be made of the faithfulness of the modulation envelope. For more precise measurements, or for complex wave forms, a different form of display can be used. This is developed in Fig. 50.

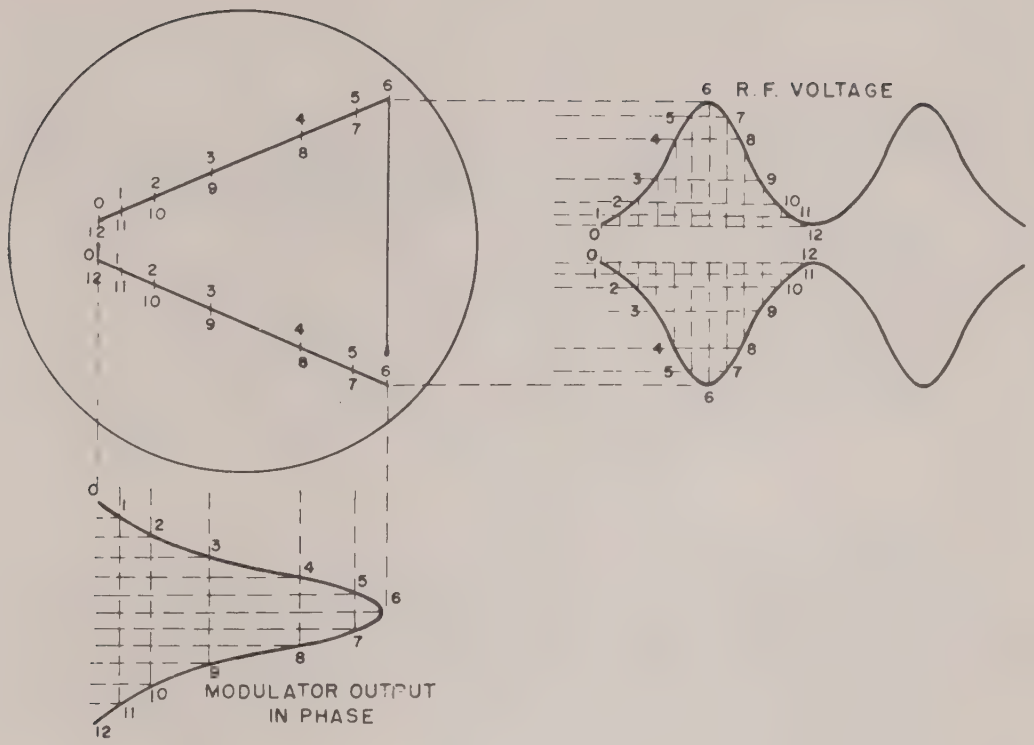
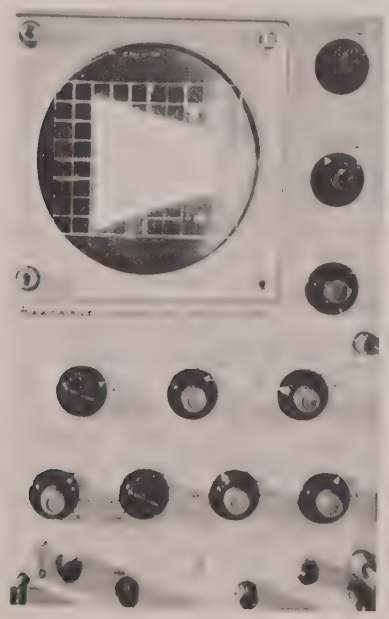


Fig. 50

By using the modulating signal to sweep the CRO, we can check the envelope against the signal which produced it. By following the "time" markings it will be apparent that any signal form should produce a straight sided trapezoid if the signal and envelope are identical. If one differs from the other, then the sides will have curvature. Try changing the shape of the RF Voltage wave form by a small amount and replotting the display.



In Fig. 51 we see an actual display of a trapezoid pattern in which the two signals are at 180 degrees instead of zero degrees.

Occasionally the modulating signal may have to be obtained from a low level stage or through an R-C voltage divider in order to obtain a safe amplitude for the CRO. In this event the phase of the modulating signal applied to the scope may not match that applied to the modulator.

Fig. 51

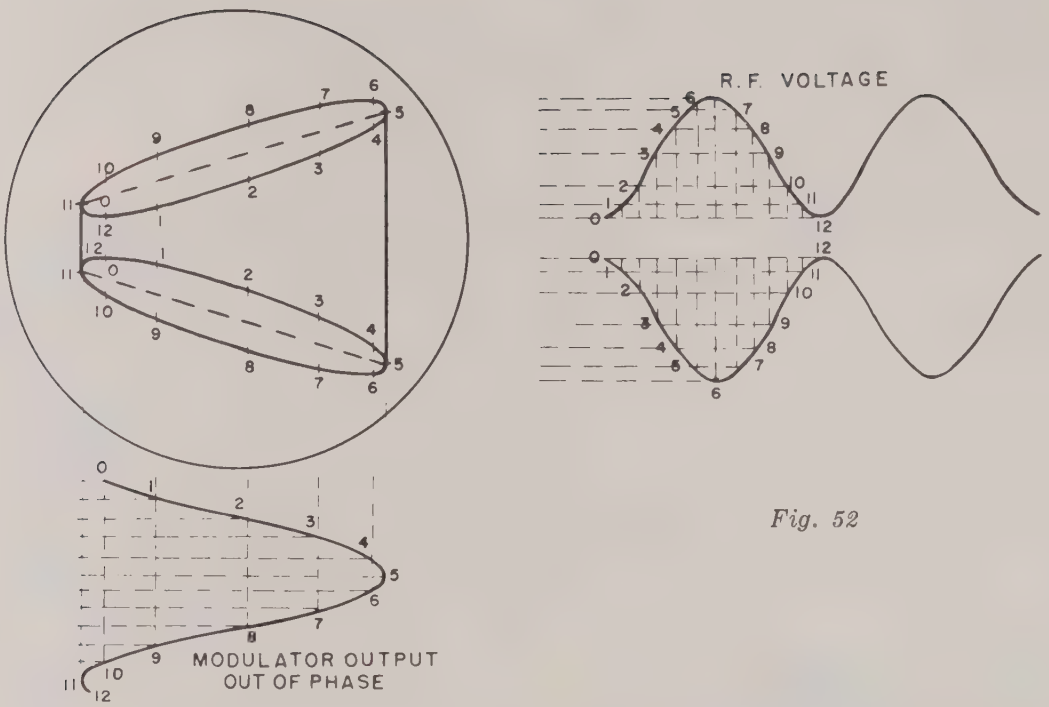


Fig. 52

In Fig. 52 we see a derivation of this situation. Notice, however, that the axis of each ellipse is still a straight line.

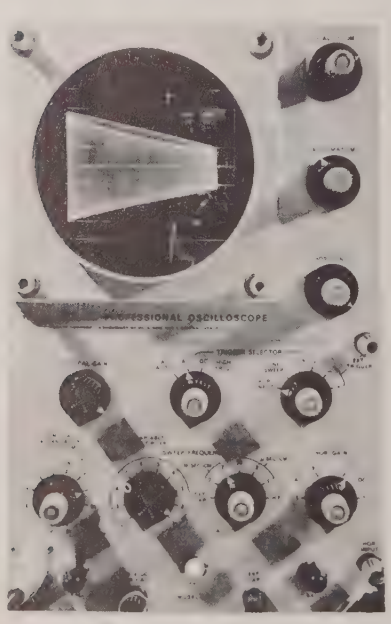


Fig. 53

In Fig. 53 we have shown an actual presentation of this type.

With experience, patterns of this form can be quickly and quantitatively analyzed and modulation system adjustments precisely made.

Methods of obtaining the signals to be applied to the scope have not been discussed since these will vary widely with the modulating system. Care should be exercised to avoid stray coupling with the test leads or direct connection to circuit points which will disturb normal operation and thus produce false displays.

For application of these techniques to radio transmitters we refer you to any current issue of the Radio Amateur's Handbook published by the ARRL in West Hartford, Conn.

Sweep Generators

We often need to know the loss, at various frequencies, through a facility or device. This is generally known as the "band-pass". We check band-pass over cable facilities, over carrier systems, through filters, through IF amplifiers and many other devices.

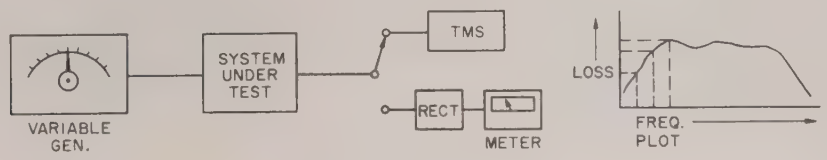


Fig. 54

For many years we used the method shown in Fig. 54. A generator was set, successively, to many frequencies over the pass band. A transmission set or a linear rectifier and meter was used to measure the relative output at each frequency and the result plotted on graph paper. Unless many points were plotted a true picture was not obtained. If many points were plotted the measurements were tedious and time consuming and there was always the possibility of a circuit change before the measurements were completed.

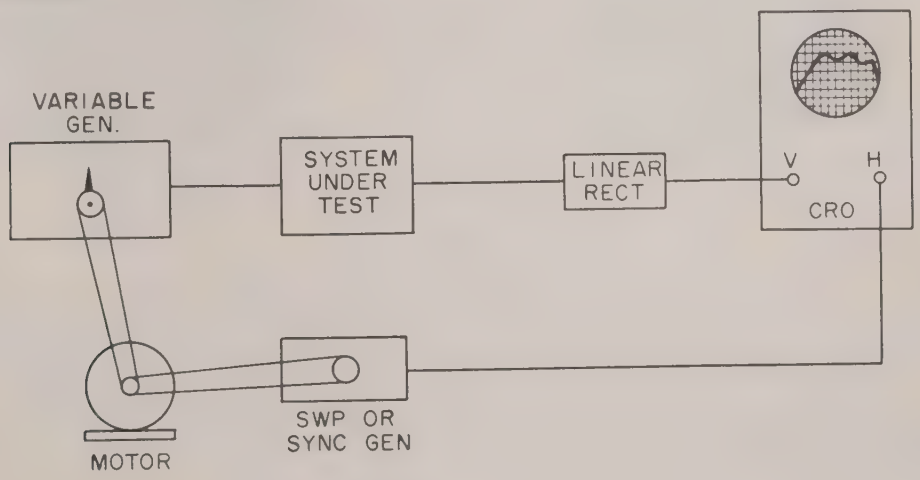


Fig. 55

In Fig. 55 we have oversimplified a "sweep" generator system. We have assumed the variable capacitor in the generator driven by a motor at a slow speed, say 40 to 60 RPM. As the capacitor rotates from maximum (low frequency) to minimum (high frequency) a voltage is generated which sweeps the CRO beam from left to right. As the capacitor moves on from minimum to maximum capacity the beam is returned at the same rate. This return sweep is usually "blanked" since the capacitor may not be symmetrical enough to produce identical traces.

This "sweep" method of checking band-pass gives an immediate, complete display of the same pattern laboriously plotted in Fig. 54.

Stringent restrictions must be placed on sweep generators to be sure that the frequency change is linear, that the output remains constant at all frequencies, etc. The sweep is actually obtained electronically in modern generators and may be sinewave, sawtooth, triangular, or of other forms. This is not critical if the same signal is used to sweep the CRO.

CRO requirements are minimal since the sweep frequencies are rectified and only the envelope is displayed. The maximum frequency the scope must handle is that of the envelope change in a low frequency sweep interval such as 60 cycles. A 500 kc scope is therefore generally adequate.

Pictures have been taken of the band pass through the 10.7 mc IF of a Heathkit FM4, FM radio tuner to illustrate the sweep technique.

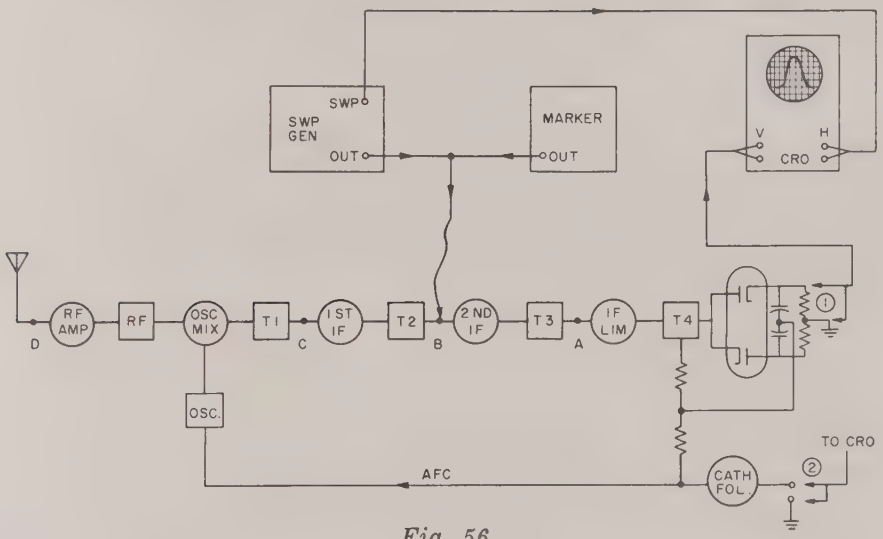


Fig. 56

In Fig. 56 is shown a block diagram of the tuner. It contains two IF amplifiers and an amplifier-limiter following an oscillator-mixer stage. The RF section operates between 88 and 108 mc while the IF section operates at 10.7 mc. By using one half of the FM detector (discriminator) a rectifier is obtained to produce the scope input. A signal generator, sweeping about a 10.7 mc center frequency can be inserted, progressively, at points A, B, C, and D for adjustment of transformers T4 through T1.

With the generator connected at point B and the CRO at point ①, we obtained Fig. 57. This shows a symmetrical band-pass with fairly steep sides.

In Fig. 58 we see the same measurement with T3 misaligned. Notice that the frequency response is no longer symmetrical and the overall gain is reduced. From this we can see that the CRO can also be used to check stage gain as well as frequency response.

Frequency Marker

Since sweep generators are not always precisely calibrated, particularly with respect to the range of the sweep, some means of identifying frequencies is desired. If a single frequency signal (marker) is introduced with the sweep signal a "beat" will be developed each time the sweep passes through the marker signal.

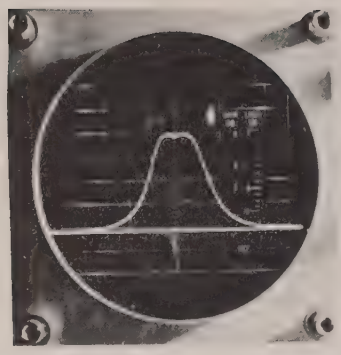


Fig. 57

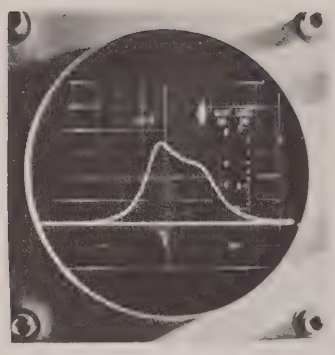


Fig. 58

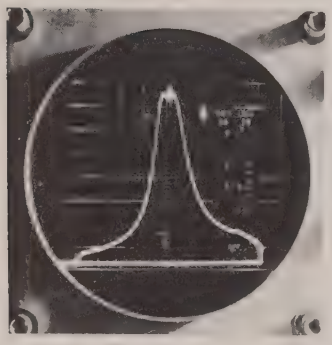


Fig. 59

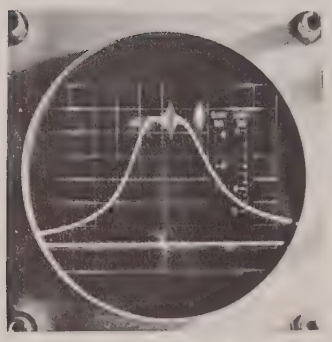


Fig. 60

Fig. 59 was taken with the signal introduced at A (Fig. 56) and the marker set at 10.7 mc. Fig. 60 was taken with signal introduced at B. The "pip" from the marker thus identifies the center of the band-pass. By changing the marker generator, the entire band-pass range can be determined by watching the position of the pip and relating to the setting of the generator.

The FM detector is a "discriminator" which produces an output proportional to the frequency applied to it. As the frequency goes above or below 10.7 mc it produces a negative or positive voltage whose amplitude is proportional to the amount the signal differs from 10.7 mc.

In Fig. 61 we see the pattern of a properly adjusted discriminator. The scope was connected to point (2) (Fig. 56) and the generator to point A. The sweep is far in excess of the useful range of the discriminator to show the full curve. Notice that the center portion is a straight line (linear) extending equal amounts above and below zero. A frequency change along this line will give faithful reproduction.

Fig. 61

Probes

It may be desirable to check points in the band-pass of a device ahead of a detector. This may be desirable when checking normal signals for distortion. In this case, a "demodulator" probe may be used on the scope.

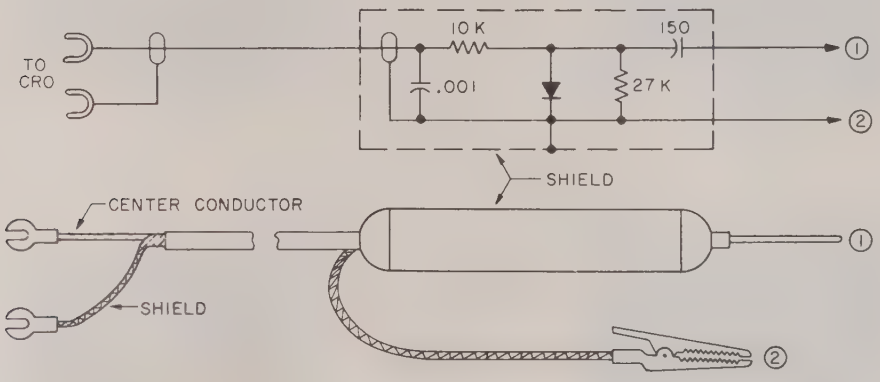


Fig. 62

In Fig. 62 is shown the circuit and general appearance of a rectifying probe which can be used with an oscilloscope.

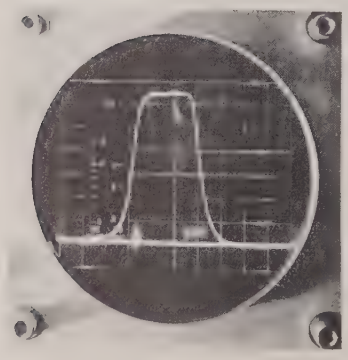


Fig. 63

In Fig. 63 we see a pattern taken with the probe of Fig. 62. The generator was applied at point C (Fig. 56) and the scope, through the probe, to point A. This pattern is similar to Fig. 57 except "upside down". The reason is that the diode in the probe is poled opposite to that in the receiver.

How It's Done

This may have sounded difficult so far, yet the main consideration in using a scope is in first understanding what significance the pattern has — that is — what should we see? Hence we have tried to first develop the pattern and then how it is checked with a CRO display.

In Fig. 64 we see the arrangement for the sweep patterns — a sweep generator with the radio chassis to its right and the CRO above. A few interconnecting cords complete the arrangement. The confusion of tools, etc., simply indicate that measurements of this type can be taken on any bench and do not require a special "laboratory" set up. The preponderant appearance of Heathkit gear in this series of articles is due to the use of the writer's personal equipment. The principles developed are applicable to all makes of equipment of this type.

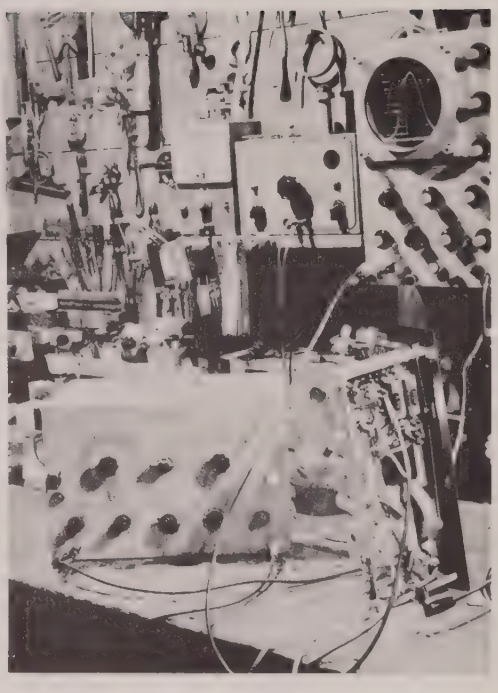


Fig. 64

Application

This "chapter" has not attempted to teach the method of adjusting modulation of a "ham" transmitter or how to line up an FM receiver. We hope we have, however, indicated the principles of certain types of scope applications. The principle remains the same whether we are sweeping a TLR-2 IF system or using a 31A visual gain set. Likewise the modulated output pattern of a transmitter or a carrier system represents a modulation process rather than a specific equipment. If we know what we should see then a CRO is an invaluable device.

Many more things could be discussed about sweep measurements such as phasing of the traces, determining of the band-pass at the 3db point, blanking of the retrace, selection of sweep rate, etc. These are generally specific to a particular system or device and could take many pages beyond the scope of this series.

PART 7

Trouble Clearing

We have previously referred to point-to-point trouble shooting. Basically this consists of looking at a circuit, a step at a time. Generally this is done in a progressive manner. An amplifier might be examined by first looking at the input and then taking a picture at the input and output of each stage, in sequence, looking for changes in wave shape or loss of gain.

All the necessary information has already been touched on in so far as the scope is concerned. It is no magic device which will automatically direct you to the source of trouble; however, used intelligently it is another valuable tool, which, like other tools must be used in its proper place.

As we have said before, the CRO is a pictorial voltmeter which will display actual waveforms, while indicating magnitudes, within its limitations of frequency response and voltage breakdown. It is particularly effective in transient and pulse type measurements. Unlike RMS-type measuring instruments it need not be used for a specified wave form, only.

Unfortunately, the CRO displays must be interpreted by the user. This means he must not only understand the CRO but also the device being tested. Displaying a waveform serves no useful purpose if we do not know the shape and/or magnitude that should be seen.

Use of Manufacturer's Data

Many manufacturers of Television receivers and several service organizations, such as Rider and Sams, provide waveforms on their circuit diagrams. Typical is the power supply diagram in Fig. 65 which depicts a common form of voltage doubler power supply.

A common trouble is excessive ripple due to faulty capacitors. The wave shapes shown, illustrate normal operation. The picture across C1 is typical of a rectified and partially filtered voltage. The picture across C2, however, can be quite misleading since it can be made to fill the screen of the CRO. The gain or input attenuator settings must therefore be checked and the amplitude of the display compared with the diagram. Notice that, although drawn and probably displayed at the same height, the input voltage has 25 times the peak-to-peak amplitude of the output voltage. The one volt p-p output is non-sinusoidal and therefore would not read correctly on an RMS meter but is in the order of 0.4V of 60 cycle a-c superimposed on a 270 volt d-c output. The diagram

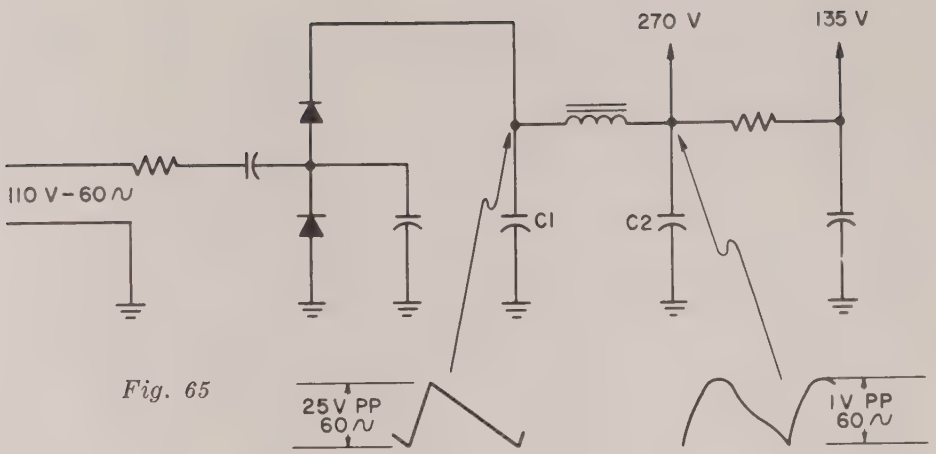


Fig. 65

thus tells that anything under this amount of "ripple" is satisfactory if we are getting the full 270 d-c volts. In this case we must know the expected a-c waveforms and amplitudes and the d-c voltage. A "leaky" C2 would show a low amplitude on the CRO pattern but would not develop the proper d-c voltage.

In Fig. 66 we see part of the vertical sweep circuit of a TV receiver and the associated waveforms.

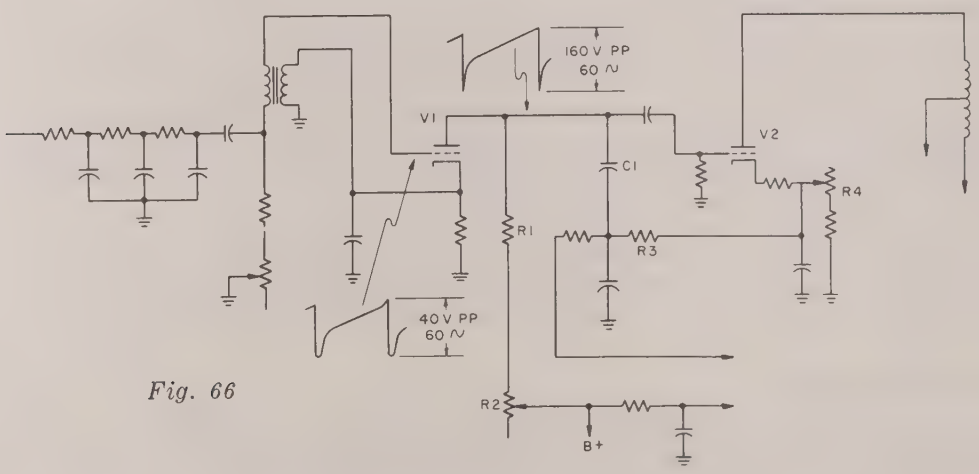


Fig. 66

Tube V1 is a blocking oscillator which the manufacturer tells us (elsewhere on the drawing) will have a rectified d-c voltage of -32 to -65 on the grid when measured with a good d-c voltmeter. Under these normal, or average conditions, a 40 volt p-p signal will be seen at this point with a CRO. These measurements can be distorted with faulty test procedures and indicate a trouble which exists only during the measurement. An excess amount of capacitance in the CRO test leads, for example, will "shunt down" the grid signal amplitude and in turn reduce the rectified d-c voltage. A CRO with insufficient band pass will flatten and round off the typical blocking oscillator spikes and likewise give a false indication. This simply emphasizes the need for

knowing both the circuit being tested and the equipment being used to make the tests. During the period that V1 is cut off by the large negative spike on its grid, C1 is charging through R1-R4. When the grid of V1 momentarily goes positive V1 conducts and discharges C1. The approximate saw-tooth waveform resulting at the plate of V1 is amplified by V2 and applied to the picture tube's vertical deflection coils.

If the output of V1 is not, at least, 160 volts p-p the picture will probably not fill the screen. If the long slope of the V1 output wave is not straight the picture will be compressed at the top (or bottom). Once more we see that we must know the circuit operation so that we can interpret symptoms in terms of the CRO displays.

With the Oscilloscope, intelligently handled, troubles can be quickly isolated to small areas of circuitry by observing waveforms and amplitudes. The usual techniques of observation (smell and feel), tube checks, voltage measurements, resistance measurements, etc., may then be applied as required. In addition interfering signals such as noise pulses, hits, etc., may be observed, with the CRO, that could not be readily found with other test instruments.

System Applications

In the TV service field, speed is an economic necessity while extreme precision is not generally a critical factor. In the Bell System, speed of restoration and routine adjustment is also important; however, the nature of our equipment and service also demands very precise measurement. We have, therefore, developed test equipment and methods for each of our instrumentalities, which assure exact performance measurements. These test instruments cannot, usually, be replaced by a scope for routine testing. A scope is subject to individual interpretation. We hope that in this series of articles we have been able to show that a CRO can prove to be a useful adjunct to this equipment.

We would certainly not suggest replacing a TMS with a CRO for calibrating a repeater, however, as indicated in the opening paragraph of this Part, the CRO could be most helpful in quickly finding and clearing a case of distortion or low gain in such a repeater.

Precautions

Marginal troubles may be overlooked since the wave shape distortion may be overlooked by the untrained eye. Equipment internal noise may be difficult to find, since several parts of the circuit may be simultaneously affected. Stage gain checks may be misleading in a stagger-tuned amplifier unless the proper test frequency is used. Test leads may introduce disturbing factors in the circuit under test and the CRO band pass may change the wave shape display.

None of these are serious problems if the CRO is used, like any other test instrument, with thought and understanding. Familiarity, gained with continued use, will continually demonstrate new and more useful applications.

The provision of data-type services such as SAGE, BMEWS, DATAPHONE, etc. is requiring the use of scopes as part of the Standard test procedures. Mr. George W. Hails, at a SAGE center in Alabama, has suggested the inclusion of some specific precautions to be observed in the applications.

Unbalanced Input

Many of our circuits have "longitudinal" voltages induced in the conductors. By the use of "balanced" operation these may be minimized. In Fig. 67 we see a balanced circuit terminated in a coil.

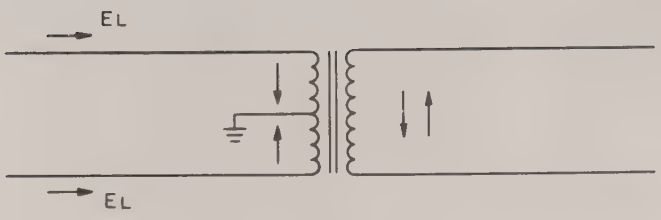


Fig. 67

This may be a balanced coil or the line may be terminated in an electronic device which accomplishes the same result in its input circuits. It can be seen that the two voltages E_L will cause current flow to ground through the center tap. Two equal and opposite, or canceling, voltages will result in the secondary.

Commercial oscilloscopes are more commonly designed for unbalanced input; that is, one side of the input is "grounded" to the case or chassis. Either through power cord filtering or through stray capacitances the case will have appreciable capacity to earth.

In Fig. 68, we see the possible result of using such a scope on a balanced pair. Part of the current is shunted from one side of the line and the two line currents (and secondary currents) are no longer equal. "Noise" will appear in the circuit and the display.

If an oscilloscope, designed for balanced input, is not available then the unbalanced input should be isolated from the circuit under test with a repeat coil. The coil must be selected to have proper frequency response, loading effect and voltage ratio.

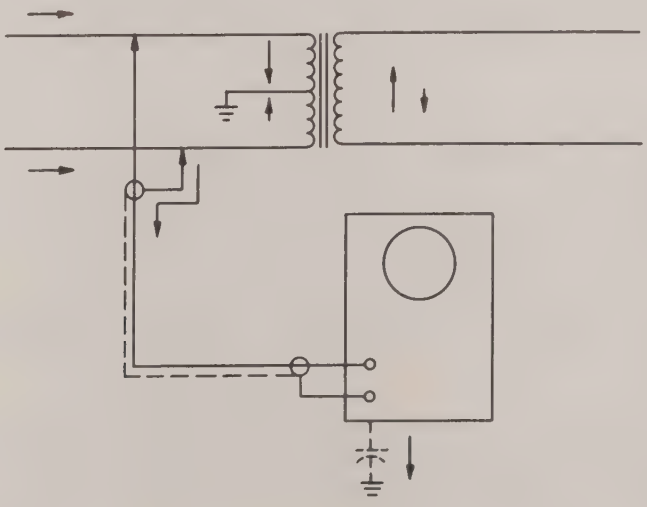


Fig. 68

For most of our work a 111C coil connected with a 1:1 ratio meets these requirements. When terminated with the input impedance of a CRO, essentially no bridging loss results to the circuit unless long test leads, cabling or patching cords are used which introduce shunt impedance. The 1:1 ratio makes correction of quantitative voltage measurements unnecessary.

Mr. Hails points out that the Dumont 304 and the KS16305 Rakscope can be used as balanced input scopes. In using the Dumont 304 this way the input attenuator is lost. In using the Rakscope he finds that the "balanced" input cannot be completely balanced by the normal adjustments. Until such time as a more satisfactory instrument is provided the 111C coil appears to be the best solution, within the limits of its frequency response.

Hits

Short duration opens, shorts, or noise "pulses" appear on a circuit as information pulses and may occur at such a time as to impair the signal. In teletype work these have been called "hits." Often these can only be seen and located with the CRO. To observe transient phenomena of this sort, a triggered sweep is used in order to obtain a stable display even though the signal repetition rate is erratic. This was discussed earlier.

Mr. Hails observes that the use of triggered sweep, when looking for momentary opens, can present problems with some scopes. Loss of trace due to the "open" may be attributed to sweep instability rather than a missing triggering voltage. He also points out that some scopes require a fair amount of triggering voltage and that some trouble signals may not be great enough to trigger the sweep. Unless you want only those signals above the threshold he recommends the use of free running sweeps for both of these situations. If the resulting pattern is too confusing due to overlays, the CRO may be carefully adjusted for positioning, focus, intensity, level, sync polarity, etc., in the free running mode and then switched to triggered sweep. In the more expensive laboratory-type CRO's such as the Tektronix this is probably less of a problem.

Probes

We have previously discussed low capacity probes and their adjustment. Mr. Hails reminds us that if a probe designed for one CRO is used with another, having a different impedance input, the attenuation multiplier will be incorrect. Wave shape will also be affected unless the compensation capacitor is readjusted. A change in the cord length will also affect this adjustment. Reference to Fig. 42 in Part 5 will make this apparent.

Phosphors

Cathode ray tubes have their faces coated with a chemical compound which glows when struck by electrons. These coatings, called phosphors, can be made to produce different durations and colors of glow. The length of time the phosphor glows, after bombardment, is called persistence. Most general purpose CRO tubes are provided with P1 or medium persistence phosphors. This is desirable for high speed or rapidly changing patterns. In making rapid changes, from one pattern to another, the old display is not retained.

Where patterns with slow repetition rates are to be observed (a few cycles per second) the first part of the sweep will be lost before the last part is completed. To display such patterns a long persistence screen (P2) is preferable. Many tubes can be obtained in different phosphors, upon request. With other tubes a change in phosphor type is accompanied by a change in the electrical connections. Mr. Hails points out that the 5ADP1 (5 inch, P1 phosphor) tube in the Dumont 304 can be replaced with a 5ADP2 with no changes.

Not all CRO's provide external capacitor connections to make possible the slow sweeps required for these long time displays. In these scopes the connections must be made internally.

Trace Appearance

The brightness of the trace and the thickness of the "line" depends upon the number of electrons bombarding the phosphor at a given instant. Thus if a high frequency signal is displayed, such as a spike, it may make a rapid and appreciable vertical excursion on the screen during a very short period of the horizontal trace time. In this case the vertical lines will be thin and light as compared to the horizontal lines. The same will be true of the vertical sides of square waves with extremely fast rise times. In some cases the vertical lines may not show at all (e.g., Fig. 37).

This condition may be confused with another in which the horizontal lines are thickened by "noise." The noise will generally be of much lower frequency and amplitude than the signal, in these cases, and will seldom be a multiple of the signal frequency. Consequently, it will appear in a different place on the horizontal trace of each successive sweep, since the sweep is timed by the signal under observation. If the sweep rate is high, phosphor persistence will retain these noise signals from sweep to sweep and the visual appearance will be a "thick" horizontal trace. This can be verified by temporarily reducing the sweep speed. This noise may be from external signals or may be low frequency components of the signal under observation. This is sometimes referred to as "grass" or "crud" in certain types of displays.

Frequency Measurements

We discussed earlier the use of Lissajous figures for making frequency measurements. Mr. Hails points out that the two signals need not necessarily be of the same waveform. He notes that an amplitude modulated carrier frequency can be checked while modulation is present. This would not be feasible with large ratios or fractional ratios (such as 3:4) unless the two signals were reasonably similar in waveform.

Transmission Monitoring

In attempting to isolate hits affecting data signals, Mr. Hails has found that monitoring the high frequency carrier line is helpful. He connects a CRO to the monitor jacks of a 37B TMS or across a Sierra Carrier Frequency Voltmeter and observes the waveforms. This is a case of combining the usefulness of a CRO and a Standard test set. (See "System Applications" above.) He points out that signal distortion will be apparent in the CRO display due to the narrow band pass of the measuring sets and this distortion must be taken into consideration. Sets with wider band pass, such as the 44B, might be more adaptable to this technique.

The Future

As we progress further into the data field and the use of solid-state devices following logic or computer techniques, pulse form transmission will require greater application of the oscilloscope. It may become as common a tool, in our offices, as the volt-ohm-milliammeter and through familiarity lose its mystery. In the meantime we trust that this review has served to stimulate interest and remove the feeling that the CRO is solely an Engineer's or laboratory technician's tool. We further hope that the discussions and examples presented here will encourage everyone to become more familiar with the potentials of this instrument. The more one uses it, the more uses one finds for a cathode ray oscilloscope.

Extra Curricular

We have had some requests, from the tinkerers! Specifically, can a CRO be used to check automotive ignition? Not only can this be done, but several commercial units are on the market. Before discussing this CRO application let's briefly review the ignition operation.

A simplified ignition system is shown in Fig. 69.

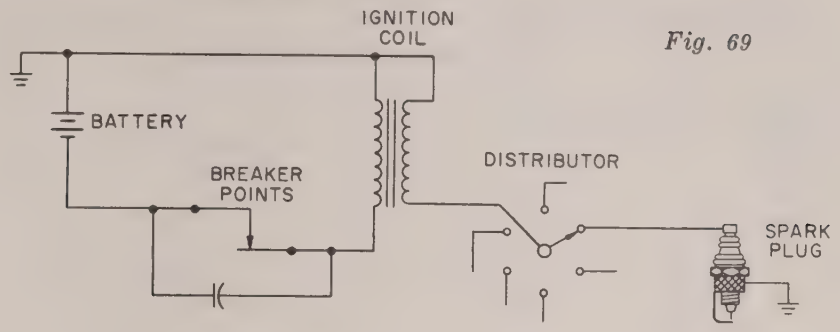


Fig. 69

The distributor rotates in synchronism with the movement of the pistons in the engine and successively connects the spark plugs to the ignition coil. The breaker points are also mechanically related so that a spark is developed in each plug at the proper time.

When the points close, current builds up through the coil primary, exponentially, as in any inductance and a large magnetic field results about this winding. When the points open, the field collapses and a high voltage is induced in the high ratio secondary. This causes an arc across the gap in the spark plug and ignites the gasoline-air vapor mixture in the cylinder. A typical firing cycle is shown in Fig. 70.

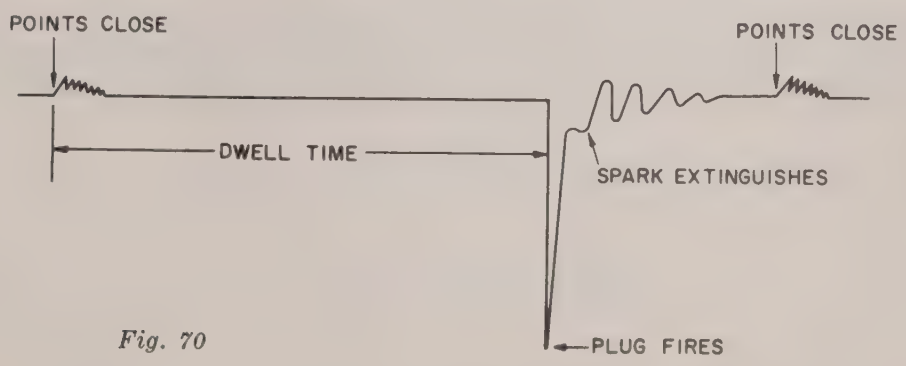


Fig. 70

As the points close, a short duration oscillation occurs in the secondary, but serves no useful purpose. The points remain closed until a spark is required. This is called the dwell time. When the points open the high secondary voltage spike causes the plug to fire, heavily loading the coil, and quickly reducing the voltage to the extinguishing point. The balance of the energy in the collapsing field is dissipated as a "damped" oscillation. A capacitor is placed across the points to prevent burning of the contacts. As the field collapses a high voltage is also induced in the primary which would tend to arc the opening points. The charging current of the capacitor lowers the voltage across the points until they are fully open.

By capacitively coupling a scope to the high voltage lead to the distributor and synching against one of the plugs this waveform can be displayed as shown in Fig. 71.

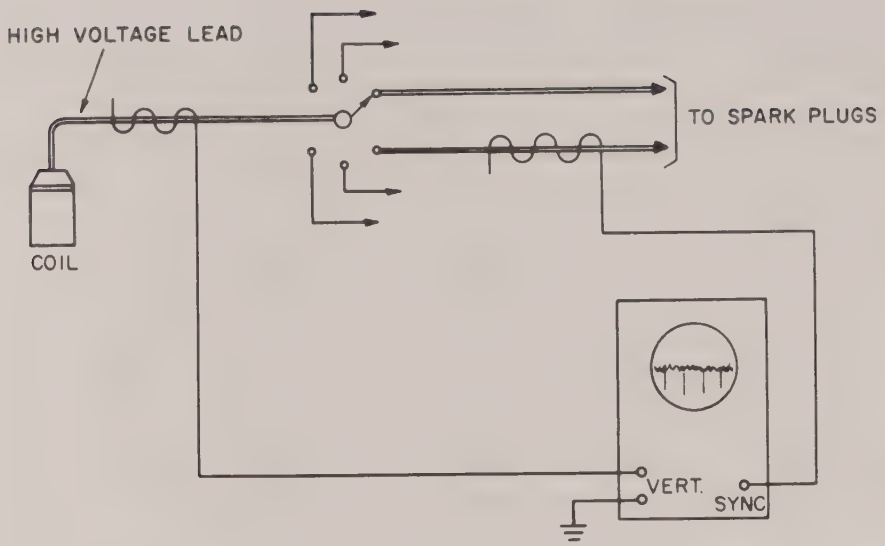


Fig. 71

By observing the display much can be discovered about dwell time, shorted or improperly gapped plugs, etc. Since the sweep is synched to a particular plug it will always be displayed first and the rest can be readily identified if the firing sequence is known.

Although this method will produce a display, it will be badly compressed when 4, 6 or 8 plug firings are placed end to end. Commercial ignition analyzers, therefore, provide a second sweep circuit which can be impressed on the scope vertical input along with the signal. This is synched with engine speed and produces successive displays, one below the other, for each plug as shown in Fig. 72.

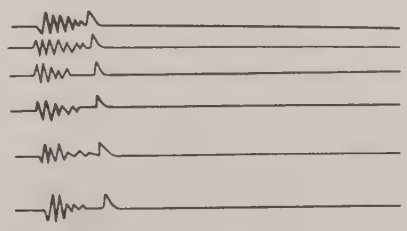


Fig. 72

A simple adapter using one dual triode electron tube and one thyratron can be constructed for use with any oscilloscope, to accomplish this display. For those interested this adapter, its use, and the display interpretation have been well covered by Mr. Dan Peters in the July 1958 issue of Radio and TV News. This magazine, now called Electronics World is published by Ziff-Davis Publishing Company, 434 South Wabash Ave., Chicago 5, Illinois. A block diagram of the adapter is shown in Fig. 73.

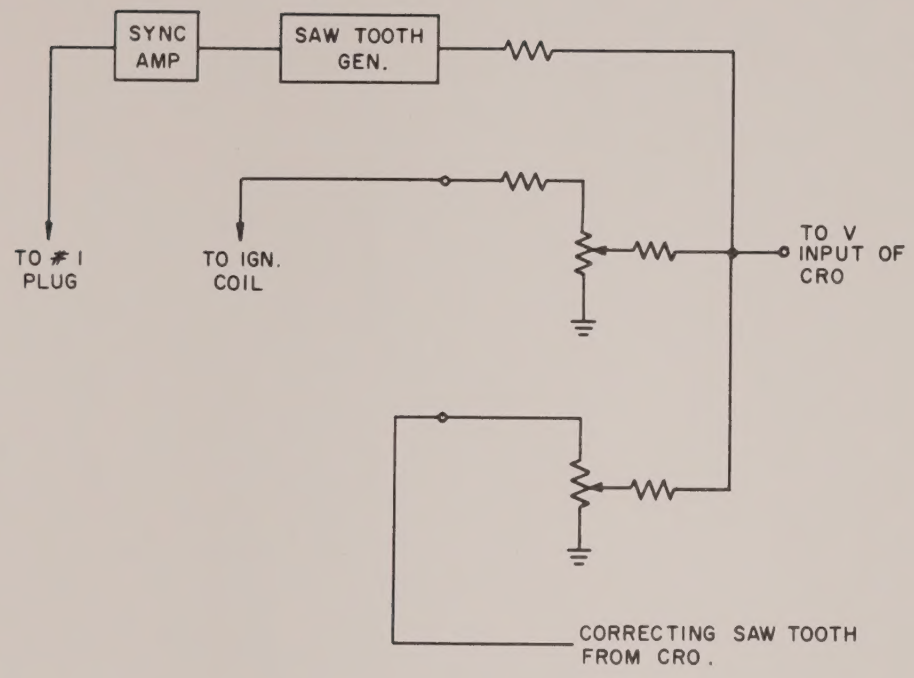


Fig. 73

The sawtooth generator moves the trace down the face of the tube similar to the vertical scan in a TV receiver. The correcting sawtooth is used to reduce the slope (of the trace) resulting from the rather rapid vertical scan. The signal is then mixed with the vertical sweep through a resistor mixer.

For the true automobile "Buff," CRO's with these circuits built in are available. Typical is the Heathkit unit which can be obtained either in kit form or already wired.

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